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THE TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS.

EDITED BY

ROBERT P. BIGELOW, Ph. D.

THE TECHNOLOGY QUARTERLY is an illustrated magazine published by the MASSACHUSETTS INSTITUTE OF TECHNOLOGY. It is devoted to original articles upon various subjects in **Architecture, Civil Engineering, Mechanical Engineering, Electrical Engineering, Physics, Chemistry, Biology, Bacteriology, Mining** and **Metallurgy,** or, in general, the **Sciences** and their applications to the **Useful Arts.** Attention is called to two especially notable features of the QUARTERLY, viz.: *The Results of Tests made in the Engineering Laboratories* and *The Review of American Chemical Research.*

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PROCEEDINGS OF THE SOCIETY OF ARTS.

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PROCEEDINGS OF THE SOCIETY OF ARTS.

THIRTY-EIGHTH YEAR, 1899–1900.

BOSTON, October 12, 1899.

THE 528th regular meeting of the SOCIETY OF ARTS was held this day at the Rogers Building, President Crafts in the chair. Twenty-five persons were present.

The records of the last meeting were read and approved. Mr. George W. Blodgett then read the report of a special meeting of the Executive Committee, accepting the resignation of the Secretary, and nominating Dr. George V. Wendell for the position. The report was accepted and Dr. Wendell was duly elected.

The President then introduced Mr. J. L. Woodbridge of the Class of '86, Stevens Institute, who read a paper on "Some Practical Applications of the Storage Battery."[1] Mr. Woodbridge began with a brief outline of the development of the storage battery, and a description of the type in most general use. This is, briefly, a grid of lead for the negative plate with square pellets of the active material, metallic lead finely divided and spongy, and a grid of lead for the positive plate with round holes filled with rolls of ribbed antimonious lead from which the oxide of lead is formed.

[1] To be published in the June number.

The greatest field of usefulness for the storage battery is found in the power plant where constantly varying demands have to be met. In the electric light plant the demand varies greatly in the different hours, and by turning the power into the battery during the time of less demand, the work is equalized. The same is true of electric railroad work where the requirements vary greatly within a few seconds. The power house must supply whatever power is demanded, and without the aid of the storage battery it would require a plant capable of supplying all that is called for at any one time. With its aid it need supply only the average amount required. By the use of the storage battery it is possible to keep the machinery running constantly at an economical point.

Several other instances were cited of the use of storage batteries to great advantage, and reference was then made to the fact that the batteries could be added to as occasion required, with only the expense of additional plates, if the tanks were made sufficiently large in the first place.

The lecturer was thanked by the President in behalf of the Society, and the meeting was then adjourned.

A. T. Hopkins,
For the Secretary.

Boston, October 26th, 1899.

The 529th regular meeting of the Society of Arts was held this day at the Rogers Building, Mr. George W. Blodgett presiding. Eighty persons were present.

The records of the last meeting were read and approved. Mr. Francis H. Boyer, Chief Engineer of the John P. Squire Company, and Mr. Gardner T. Vorhees, Refrigerator Engineer, Boston, were elected to Associate Membership.

The Chairman introduced Mr. H. C. Spaulding, of the Massachusetts Institute of Technology, '87, who read a paper on "Visual Signals." The speaker began by defining signalling as a sign agreed upon, understood, or designed to be understood and used to convey information, especially at a distance.

The first real attempt to signal made use of lights on upright supports, the position of the lights corresponding to letters of the

alphabet. In 1455 the Scotch Parliament passed a law that burning bales should be used to announce the approach of the enemy. Later a system of signalling was introduced between Paris and Lille, consisting of two vanes on the end of a horizontal arm, the relative position of the vanes having a definite significance. At night lights were used. This was followed by the clock-vane system, and later by the electric telegraph.

The wig-wag system used by the army and navy is an outgrowth of the system devised by Major Myer, the motion of a square flag on a white staff. The present army and navy system makes use of flags, heliograph, field telegraph and telephone, torch, flash lantern, rockets, bombs and searchlight.

The kosten signals were mentioned. Different colors represent different numerals, which in turn have a meaning. The colors are made by automatic firing of cartridge cylinders containing the substance producing the colored lights.

The Weather Bureau and wind signals consist of a series of flags, whose form, color, or arrangement of colors have a definite meaning. The international code is also a flag system.

Mr. Spaulding gave a short sketch of the earlier methods of railroad signalling, then described the semaphore, an apparatus for making signals, especially with movable arms, disks and lights. A number of views of the signal system used at the South Terminal Station were shown, also views illustrating the use of the block signals. The block system is a method of controlling railroad trains which are moving in the same direction on the same track, so as to prevent collisions. The automatic block signals are controlled electrically.

The main objection to the use of flags is that they may be obscured in action due to the direction of the wind. To obviate this, Mr. Spaulding explained an instrument which he has devised called the "Telegnophore." It consists of a hollow cylinder, the surface being made of vertical rotating prisms whose sides are red, white and blue, respectively. The color of the surface may be altered by rotating the prisms, the rotation being controlled by electro-magnets in the center of the cylinder.

A short discussion followed. The thanks of the Society were extended to Mr. Spaulding for his interesting paper, after which the meeting adjourned.

BOSTON, November 9, 1899.

The 530th regular meeting of the SOCIETY OF ARTS was held this day at the Rogers Building, President Crafts presiding. Thirty-five persons were present. The records of the previous meeting were read and approved.

The President then introduced Mr. A. Lawrence Rotch, Director of the Blue Hill Observatory, who spoke on "Use of Kites to Obtain Meteorological Data."[1]

Mr. Rotch told of the early observations carried on at high altitudes, such as high mountains or lofty plateaus, and of the great expense incurred in the equipment and maintenance of the same. Views were shown of a number of these observations, among them the following: Mt. Washington, Pike's Peak, one in England at which hourly observations have been made during the last fifteen years, one in France, Switzerland, and Germany.

The great objection to such stations for meteorological purposes is that the records do not represent the conditions in free air. The radiation of heat during the day and cooling at night, generate currents of heat which do not exist in free air.

Balloons have been used for many years, but the measurements have been of little value to meteorology. A Harvard graduate, Dr. Jeffries, made the first scientific balloon voyage, during which the temperature of the air, the barometric pressure, humidity, and velocity of the wind were recorded. Samples of the air were also taken. Later ascensions have added little to these results.

The main objections to balloons are: danger to life; impossibility of obtaining measurements at different altitudes on the same vertical; finally, the fact that the basket of the balloon carries with it the air from the ground. In Europe unmanned balloons are extensively used for the highest strata. The balloons carry instruments for automatically recording the various quantities desired, and these records are studied when the balloon falls to earth. The highest records correspond to an elevation of ten miles. The results are, however, of little service to the meteorologist.

The chief advantages in the use of kites are: they cost less and are free from danger; a balloon drifts with the current, whereas a kite remains practically in a constant position with reference to the observer; moreover, a series of kites strung at various points of the

[1] To be published in the June number.

cord allow observations to be made at different elevations simultaneously.

Mr. Rotch gave a short outline of the early history of kite flying, beginning with some temperature measurements made with kites by Dr. Wilson, of Glasgow, in 1749, to the revival in their use by Mr. Archibald in 1883, for studying wind velocities. In August, 1894, Mr. Eddy began his experiments at Blue Hill, and much credit is due him for awakening an interest, and for demonstrating the value of the kite in meteorological work.

At present the Hargrave box kite is almost exclusively used at the Blue Hill Observatory. Instead of being flat and tapering at the lower end, these kites are box-shaped, with their ends open and the sides covered with some strong, light material. The flying angle is 50° to 60° to the horizon, and can be raised when the wind is stronger than 12 miles per hour. The position of the kite is measured by a transit. The kites carry instruments which record automatically, temperature, humidity, barometric pressure, and wind velocity. The highest altitude yet attained at Blue Hill is 12,440 feet; the time of flight often lasts 12 hours.

A number of diagrams of the results of such observations were shown. As a rule, the temperature falls adiabatically with the ascent to a certain point, where an inversion or increase of temperature takes place, followed later by a gradual cooling of the layers. The fall by day is approximately 1° for every 3 feet. At night the temperature rises with the altitude until a height of 200 or 300 meters is reached then falls. The air is usually dryer by night than by day.

A few photographs were shown of the Blue Hill Observatory, taken by means of a camera fastened to the kite, and it is hoped that valuable photographs of the tops of clouds may be obtained in this way.

The thanks of the Society were extended to Mr. Rotch for his very interesting paper, after which the Society adjourned.

BOSTON, November 23, 1899.

The 531st regular meeting of the SOCIETY OF ARTS was held on this day in the Rogers Building at 8 o'clock. President Crafts presided. Sixty persons were present.

The records of the previous meeting were read and approved. Mr. H. B. Adams, of Cambridge, was elected to Associate Membership. After the announcement of the subject for the next meeting, the President introduced Mr. A. D. Little, of the Massachusetts Institute of Technology, '85, who gave a most interesting address on "New Cellulose Industries."[1]

Mr. Little said cellulose has been properly called the structural basis of the vegetable world, and it is elaborated in an immense amount for the purposes of the growing plant. The unit of plant structure is the cell, and the cell wall is made up of pure cellulose, which, during the growth of the plant, may become infiltrated with other substances so that the plant cells, according to their functions, may assume or have impressed upon them an almost infinite variety of form. Notwithstanding the limitations to the use of cellulose, owing to this fibrous or cellular structure, it occupies a position of tremendous importance in the commercial and industrial world.

The cellulose industries are: lumbering and working of wood, manufacture of wood pulp and paper, raising, preparing and spinning of cotton, manufacture of cordage, smokeless powder, parchment paper, lamp filaments, etc.

Cellulose is a colorless, translucent, flexible solid, heavier than water, strong and tough. It is stable under ordinary conditions, takes dyes brilliantly, is easily polished, and in dense forms is hard and rigid. In itself it is structureless, but owing to its origin, it is almost entirely used in form of little tubes or fibers. This structural condition has limited, as said before, its use, and the object of the new process to be described is to remove these limitations as to form by making, for every practical purpose, the cellulose itself soluble in water and plastic.

Mr. Little then explained the method of obtaining the *new compound*, cellulose sulpho-carbonate, discovered by Cross, Bevan, and Beadle, of London, in 1892. This substance, known commercially as *viscose*, is soluble in water, extremely plastic, and can be easily decomposed with recovery of the original cellulose. The recovered cellulose, moreover, retains the form impressed upon the plastic compound. Sulpho-carbonate, or viscose, is formed by exposing ordinary fibrous cellulose, while still moist with strong caustic soda, to the vapor of bisulphide of carbon.

[1] Published in full on page 12.

Another property of the viscose solution is its great viscosity. A solution of cellulose sulpho-carbonate may be mixed with other inert materials, as clay, graphite, powdered coal, and pigments, which materials are held firmly entangled by the cellulose after the viscose is decomposed. These materials form a part of the final substance, and so modify its properties.

Mr. Little spoke of the immense industrial importance of the new discovery, and spoke of the recognition which it is receiving in England and on the continent of Europe. Among some of the new applications:

(1) Application of the films and filaments of the recovered cellulose, bags, wrapping for butter, artificial flowers.

(2) Application of the recovered cellulose in admixtures with other material, as with clay, coal tar and rubber, forming mackintosh cloths, bicycle tires, rods and dishes resembling vulcanite, billiard balls, etc.

(3) Applications of viscose solution for paper sizing, cloth finishing, and viscose paint.

(4) In the manufacture of new compounds formed or derived from the recovered cellulose; for instance, cellulose-acetate.

Mr. Little also spoke of the present method of producing artificial silks. It depends on the fact that the lower nitrates of cellulose are very soluble in a mixture of alcohol and ether, but insoluble in water. Such a mixture is forced through very fine capillary tubes under great pressure, and on falling into water, very fine filaments of nitro-cellulose are formed. The filaments are then spun, and afterwards denitrated to render them less combustible. Silks produced in this way possess a wonderfully beautiful luster, but are not so strong and durable as the ordinary silks. Their main use lies in obtaining decorative effects.

At present a process is being prepared at Kew for applying viscose instead of the nitro-cellulose. Viscose solution has the advantage of being much cheaper than nitro-cellulose solutions, and of yielding a pure cellulose without denitration. The solution is pressed through fine capillary tubes into a solution of ammonium-chloride in which the viscose coagulates immediately without decomposition. The filaments are then formed into a compound thread which are twisted and afterwards wound on bobbins. The cellulose is recovered by im-

mersing these bobbins in boiling brine. A very large assortment of viscose products were shown to the great profit and pleasure of the audience.

The thanks of the Society were extended to Mr. Little for his exceedingly instructive address, after which the meeting adjourned.

BOSTON, December 14, 1899.

The 532d regular meeting of the SOCIETY OF ARTS was held on this day at 8 o'clock, in the rooms of the Geological Department, Pierce Building. President Crafts presided. Sixty persons were present.

The report of the previous meeting was read and approved. Mr. A. F. Bemis was elected to Associate Membership. After the announcement of the subject for the following meeting, the President introduced Professor Niles. The latter, after referring to the pleasure of entertaining the Society in the rooms of the Department, spoke of the origin of the mineralogical and geological collections of the Institute, and emphasized the fact that the collection had been made solely with regard to the needs of the students; in fact, a large number of specimens had been collected by the professors and students themselves. The specimens are arranged in drawers or trays, which may easily be carried to the desk, where the student may study them individually.

Professor Niles then spoke of the valuable collection of minerals and building stones to be exhibited after the lecture, which had been made by Professor Crosby and Mr. Fuller, in association with the Commissioners of Massachusetts and the United States, for the Paris Exposition of 1900. The commission was desirous of sending to the Paris Exposition as representative a collection of minerals and building stones of the United States as possible, and every effort has been made to obtain that result.

This collection is to be presented to the Institute at the close of the Exposition. Professor Niles emphasized its value to the students of architecture and mining engineering, to whom a knowledge of stones and quarries of this country is of such great importance, and mentioned that during the last few years the attention of builders had been drawn to the need of a thorough investigation of the effects of

temperature and pressure on the durability of the stones. It has been found dangerous to rely entirely upon chemical analysis as a test of the durability, since the physical condition or structure has been shown to exert a very marked influence. Another question to be studied, is the effect of pressure on building stones.

Professor Crosby was introduced, and mentioned that the Institute had been asked to make a collection of the phosphates and carbonates of this country. He drew particular attention to the beautiful specimens of calcite from Missouri, and of malachite from Arizona.

Mr. Fuller, of the Geological Department, gave an interesting account of the methods which he had adopted for collecting the building stones. The quarrymen were invited to send samples of granite, marbles, limestones, sandstones, slates, and soapstones, and their responses were very cordial. The stones for decorative purposes are finished in rectangular slabs, highly polished, the building stones in the form of cubes, the six faces being differently dressed.

After the adjournment of the meeting, those present gladly availed themselves of the opportunity to inspect the valuable and well-arranged collections, information being most kindly given by the members of the geological department.

One of the pleasantest features of the evening was the delightful informal reception tendered by Professor Niles to the ladies and members in the Margaret Cheney Room.

BOSTON, December 28, 1899.

The 533d regular meeting of the SOCIETY OF ARTS was held at the Institute, Rogers Building, this day at 8 P.M. Thirty-three persons were present.

The report of the last meeting was read and approved.

Mr. Albert E. Leach, of the Massachusetts Institute of Technology, '86, Analyst State Board of Health, was introduced, and gave a most interesting and valuable address on "The Character and Extent of Food and Drug Adulteration in Massachusetts, and the System of Inspection of the State Board of Health."

After referring to the general misconception of the nature of food and drug adulterations, Mr. Leach spoke of the improvement which had taken place during the last few years, owing to the efforts of the

United States Government and the various states in the interest of pure food.

Mr. Wedderburn, of the Department of Agriculture, estimates the food adulterations throughout the states to be under 15 per cent., a very excellent record when it is remembered that in only six states, Massachusetts, New York, Pennsylvania, New Jersey, Ohio and Michigan, laws have been enacted and enforced for the restriction of food adulteration.

In this state the law is very strict, the addition of any foreign substance rendering the vender liable to a fine of $50 for the first offence, $100 for the second, and both fine and imprisonment for the third.

In 1883, the Massachusetts State Board of Health established the Department of Food and Drug Inspection, and appropriated a certain sum for the collection of samples, and for their analyzation. The analyses were at first made by paid analysts in their own laboratories, but in 1891 an analyst was chosen, and a State Laboratory founded. The present finely equipped laboratories are in the new portion of the State House.

Mr. Leach spoke of the methods of collecting and analyzing samples, and specified what legally constitutes an adulteration of food.[1]

Three-fifths of the appropriation in this state is, by law, devoted to the examination and collection of milk and milk products. The most common forms of adulteration in milk are watering and skimming, although coloring matter is frequently added. During the last few years, owing to its antiseptic properties, formaldehyde has been added to milk; 1 part in 5,000 has been shown to keep milk sweet for eight days, whereas the untreated product curdles in two. Not alone in milk, but also in many substances the use of preservatives, boracic acid and salicylic acid, is on the increase; for instance, in catsup, salt codfish, tripe, oysters and sausages.

Mr. Leach gave as the other foods most frequently adulterated: vinegar, chocolate preparations, honey, olive oil, maple sugar, spices, coffee, lard, molasses, and cream-of-tartar. A very large assortment of foods was shown; among the most interesting were the artificial coffee bean which can only be detected by the microscope, although

[1] Published in full on page 22.

made of roasted wheat; currant jelly made of apple juice; honey containing the honeycomb and dead bees, though wholly made of glucose; and olive oil made of cotton-seed oil.

Finally the subject of drugs was considered. A drug is said to be adulterated when it is sold by a name recognized in the United States Pharmacopœia or in any standard work on Materia Medica, and does not conform with the standard fixed by such works. Among some of the preparations most liable to fall below the standard are ammonia, distilled water, tincture of opium, and powdered opium. Drugs may contain impurities which enter accidentally during the process of manufacture. For instance, arsenic is often found in glycerine.

A short discussion followed. The thanks of the Society were extended to Mr. Leach for the very instructive paper, after which the meeting adjourned.

GEORGE V. WENDELL, *Secretary.*

NEW CELLULOSE INDUSTRIES.

By A. D. LITTLE.

Read November 23, 1899.

As we have to consider to-night certain new industries based upon recent developments in the chemistry of cellulose, you will perhaps pardon me if by way of introduction, I ask you to recall some of the well-known facts regarding cellulose itself, and its chief chemical relationships.

Cellulose has been properly called the structural basis of the vegetable world, and it is elaborated in immense amount for the purposes of the growing plant. The unit of plant structure is a cell, and the cell wall is made up of cellulose, which in the first instance is nearly or quite pure. Sometimes, as in the case of the cotton fiber, it remains nearly pure in the mature cell wall, but more commonly, as growth goes on, other substances are infiltrated upon it and become a portion of the wall, modifying by their presence the properties of the cellulose. The wood of cone-bearing trees contains, for example, only about 50 per cent. of cellulose, which is recovered nearly pure in the chemical processes for the manufacture of wood fiber.

As the plant cells according to their function may assume, or have impressed upon them, an almost infinite variety of form, it follows that cellulose, as it is supplied by nature, embodies this diversity. It is, however, always in its natural state, subject to the limitations of its availability and usefulness which are imposed upon it by the cellular or fibrous structure of the plant. In spite of these limitations, cellulose is to-day the chief raw material of the world. To-night I hope to describe a process by which these limitations are removed for what is, in any practical or general sense, the first time — a process which in effect makes cellulose soluble in water, and as plastic as potter's clay.

Some idea of the true position of cellulose in commerce and industry, and of its influence upon the whole social economy of the world may be obtained if you consider for a moment what the cellu-

lose industries are. They include lumbering and the working of wood; the manufacture of wood pulp and paper; the raising, preparing, spinning and weaving of the textile fibers, as cotton, linen and jute; the manufacture of cordage from the so-called hard fibers, like sisal, hemp and manila; together with the multitude of lesser industries concerned in the manufacture of celluloid, smokeless powder, pyroxylin varnishes, vulcanized fiber, parchment paper, lamp filaments, and so on. It is obvious that no raw material could have reached a position so commanding except through its possession of many desirable and useful properties.

Cellulose is a flexible, colorless, translucent, lustrous solid, about one and a half times as heavy as water, and remarkably strong and tough. In certain of its forms it has shown a tensile strength equal to that of good steel on equal sections. It is stable under the ordinary conditions of use, and very durable. It takes dyes brilliantly, may be polished easily, and in its denser forms is hard and rigid.

Cellulose itself is structureless, but by reason of its origin and the limitations of our knowledge as to how it could be worked, it commonly occurs and has been almost wholly utilized in the shape of little tubes or fibers, or of structures built up from them. In the new industries to which I am about to call your attention, we have to consider the substance itself without respect to form.

A few years ago I had the pleasure of laying before this Society some of the experimental results which had then been developed from the remarkable discovery made by my friends, Messrs. Cross, Bevan, and Beadle, of London, in 1892, that when ordinary fibrous cellulose is first wet with a strong solution of caustic soda, and thereafter, while still moist, exposed to the vapor of bisulphide of carbon, a new compound, known as cellulose sulpho-carbonate is formed, which is soluble in water and extremely plastic, and which, moreover, may be readily decomposed with recovery of the original cellulose slightly modified in character and in the form impressed upon the plastic compound. The cellulose sulpho-carbonate, or cellulose xanthate as it is sometimes called, has received the commercial name of viscose.

The immense industrial importance of this discovery is rapidly becoming apparent, more especially in England and on the continent of Europe, where practically all of its commercial applications have been thus far developed. This importance rests upon the fact that the viscose process, for every practical purpose, is a process of render-

ing cellulose itself soluble and plastic, and thereby removing all limitation as to form. As a result, a new and rapidly expanding group of cellulose industries has arisen, and already the commercial applications of the process are going forward upon the most divergent and apparently unrelated lines. These new applications may be broadly grouped into: —

Applications of the viscose solution, such as paper sizing, cloth finishing, and viscose paint;

Applications of the films and filaments of recovered cellulose;

Applications of the recovered cellulose in admixtures with other materials, as with clay, coal tar, and rubber;

The manufacture of new compounds formed or derived from the recovered cellulose, as, for example, cellulose acetate.

In all, about twenty-two different applications at present claim attention.

The use of viscose in paper making depends upon the fact that when a solution of the cellulose sulpho-carbonate is added to the mixture of stock in the paper engine, and the sulpho-carbonate then decomposed by the addition of Epsom salts, the recovered cellulose is precipitated throughout the material in the engine in the form of fine flocks which closely resemble hydrated alumina in appearance, and which are so gelatinous and adhesive as to attach themselves to the fibers, binding and cementing these together in the subsequent processes of paper making. The addition in this way of from 1 to 4 per cent. of cellulose to the paper, results in a notable increase in strength and elasticity.

The quality of the paper thus produced has led to its employment as the basis for artificial leathers for use in book binding, box making, and so on. The paper is first coated with a surface color, which is followed by a coat of a special size, after which the paper is dried and varnished. It is embossed by passing between heated rollers upon which the design has been sunk.

The advantages obtained through the use of viscose in paper sizing have led to its similar use in the manufacture of the so-called leather boards. Here again the solution is placed in the engine with the stock, and decomposed by the addition of Epsom salts, after which the stock is run off on the board machine in the usual way. The product is a board of remarkable toughness and exceptional strength.

The great viscosity of the solution of cellulose sulpho-carbonate makes it an admirable vehicle for carrying any inert material, any such additions being afterward entangled and firmly held by the recovered cellulose when the sulpho-carbonate is decomposed. One part of cellulose will in this way easily carry and hold fifteen parts of clay. These facts have been utilized in the preparation of the coated papers commonly used in the magazines and elsewhere for fine printing, and especially for half-tone work. Such papers are usually coated with mixtures of clay, zinc oxide, and glue, but distinctly better results are secured when the viscose solution is substituted for the glue. The coated paper thus prepared has an especially good feel, good color, no uuusual odor, and a very fine, smooth surface which takes all cuts particularly well. The particular merit of the paper is to be found in the fact that these results are secured without high glaze, and consequently with much less reflection of light from the surface than is usual in such papers.

There is a peculiar appropriateness in the application of viscose to the sizing and finishing of cotton yarn and cloth, for the reason that after the cloth or yarn has been saturated with the solution and the latter decomposed, a film of cellulose is left upon the fibers, which by joining them together gives increased strength, while by filling up their inequalities of surface, an increased luster is obtained. Thus by the addition of cellulose to the cellulose of the cloth itself, ordinary cotton cloth may be made to closely resemble linen.

Heavier coatings of cellulose, which in this case may be mixed with clay or pigments, have been applied for the production of cotton cloth and cloth for book binding. The advantages here are great by reason of the completeness with which the cloth can be filled, the hardness of the surface obtained, and the absence of all tackiness should the cloth become damp in use.

The ability of the viscose solution to carry pigments which are afterwards held by the recovered cellulose has been further utilized in color printing upon cloth. Here again it is particularly advantageous that the binding material is chemically substantially the same thing as the substance of the cloth itself. The pigments are much more firmly fixed, and it becomes possible to obtain certain effects which are otherwise impossible. If the viscose solution is used alone, the printed portions of the cloth take dyes more deeply and brilliantly than the unprinted parts, so that, if the printed cloth is afterwards

passed through a dye bath, the pattern stands out in darker tones upon a comparatively light ground.

From color printing to ordinary painting is a somewhat long step, but the comparatively short life of the viscose solution and its pronounced color introduced technical difficulties of some magnitude which required to be overcome before any general use could be made of viscose paint. These difficulties have recently been successfully met in Paris, where already a considerable and rapidly extending use is being made of the material in this direction. A 10 per cent. solution of viscose, so prepared as to keep for several weeks, is used as the vehicle for paint, and this is now being applied upon a considerable scale to the Exposition buildings. The alkalinity of the solution, and the presence of sulphur compounds restrict somewhat the number of pigments which are available, but a sufficient number of cheap pigments are unaffected to enable one to obtain any desired shade by proper mixtures. The paint is, of course, diluted with water to the desired consistency, and is applied with a brush made of vegetable fiber instead of bristles. The paint spreads with extreme ease, and its covering power is much in excess of that of oil paint. It may be easily rubbed down, and then gives with varnish, an especially smooth, soft finish. The ratio of pigment to cellulose is as fifteen to one, and the cost price of the entire paint is about 8 centimes per kilo. Soon after the paint has been applied, the viscose solution dries down and decomposes, so that the pigment is firmly held in place by the film of recovered cellulose.

Another important application of the viscose solution has been made in Paris, which is curiously divergent from the foregoing. Under the name of clyzol, the solution has been put upon the market there for the purpose of removing old oil paint. If this solution is applied to a painted surface of wood or iron, upon which there may be even as many as fifteen or twenty coats of old oil paint, a saponification of the oxidized oil is almost immediately effected, with the result that when the viscose dries down and decomposes, the film of recovered cellulose may be stripped away, carrying with it all the paint, and leaving the wood or metal clean. It is not even necessary to wait for the solution to dry, since, after it has been in contact with the paint for about ten minutes, a stream of water is sufficient to wash the whole away. Clyzol has been adopted by the Paris Omnibus Company among other large users, and would seem to have a wide

application in the cleaning of rolling stock and large iron structures, before repainting. Many of the beautifully carved old oak doors in Paris, which at some period of bad taste had been painted, are now being cleaned with clyzol and refinished in their natural state.

The manufacture of thin films of cellulose in continuous lengths has been developed in Manchester, England, where the viscose solution is allowed to flow in a carefully regulated stream upon a heated and very smooth iron cylinder which slowly revolves the while. The solution dries down into a film upon the cylinder, from which it is then stripped off and reeled. The heat has, however, been insufficient to decompose the viscose, and the decomposition is, therefore, subsequently effected by treating the viscose film with boiling brine. The inorganic by-products diffuse out into the brine and the clear film of cellulose remains. These films are extremely tough and strong, and are destined to find a varied and wide application in the arts. They form an ideal material for use in dialyzing apparatus, and should ultimately replace parchment paper for nearly all purposes by reason of their greater thinness, better appearance and superior strength.

The preparation of thicker sheets of cellulose, having the general appearance and physical properties of sheets of celluloid, is still in the experimental stage of its development, but enough has been accomplished to prove that it is merely a question of a little time before such sheets, rivalling celluloid in beauty and variety, will be upon the market at a fraction of the cost of celluloid, and as free from danger as ordinary cardboard. These sheets, however, are much more susceptible to the action of moisture than celluloid itself, and for this reason cannot compete with celluloid in all directions.

One of the first uses to which the thin films of cellulose have been applied is in the production of artificial flowers at Breslau. I do not claim to be an expert in this particular matter, and any opinion which I may express is subject to correction by the better informed, but to my masculine eyes the flowers appear stiff and glassy. The leaves are much more satisfactory, and it is hoped that by making the films somewhat more soft in texture, much better results generally will be obtained.

One of the most ingenious of all the developments of viscose, although at present one of the least important technically, is to be noted in the process of splitting cellulose films, as discovered and worked out by Mr. Thomas, at Paris. The viscose film is first formed

and allowed to gelatinize, after which it is soaked in brine to effect a further coagulation and hardening. It is then transferred to another solution, which effects almost at once a superficial decomposition of the viscose, the result being that, if a tube is inserted anywhere at the edge of the film and air blown in, the film at once splits on a plane parallel to its surfaces, and may be blown out into a bag or tube, or into irregular shapes if the original film was first cut into the proper form. It is proposed to utilize the process in the manufacture of sausage casings, packages for snuff, tobacco, etc., and also as covering for handles upon which the split film shrinks tightly, giving a finish like rawhide.

An especially important and interesting new cellulose industry involves the several processes by which the so-called artificial silk is now produced in quantity. A great deal has been said and written about this new product, in spite of which there exists nearly everywhere a complete misconception of its true character and position. Much of this misconception is due to the fact that the whole position of the industry and the whole character of the product has radically changed since May, 1898, so that conclusions based upon these earlier results are falsified to-day.

The present commercial processes for the manufacture of artificial silk depend upon the solubility of the lower nitrates of cellulose in a mixture of alcohol and ether, and upon the fact that when this solution is brought into contact with water, the nitrocellulose is precipitated. The solution is, therefore, forced into water through fine capillary apertures or spinning tubes under heavy pressure. As soon as the solution strikes the water, a filament of nitrocellulose is produced, which is drawn away from the spinning tube at the rate of about 600 meters an hour. In the process worked out by Chardonet, a simple nitrocellulose solution in the ether-alcohol mixture is employed, but owing to its viscosity it requires extremely heavy pressures to force it through the tubes. The Chardonet solution formerly contained from 7 to 8 per cent. of cellulose nitrate, but has now been brought up to about 13 per cent. An important improvement in the process was introduced by Lehner, who found that the addition of sulphuric acid to the collodion, that is, the cellulose nitrate solution, greatly lowered its viscosity and permitted the use of a 15 per cent. solution under much lower pressures than those required without this addition.

The extreme inflammability of the cellulose nitrates in themselves, and especially when in this form, would preclude their use in artificial silk were it not for the fact that, by treatment with appropriate reducing agents, the nitric acid may be removed and the filaments converted into ordinary cellulose after the manner worked out by Weston in preparation of his tamidine in 1882. The filaments, after spinning, are therefore denitrated and then subjected to a further treatment with aluminum acetate to render them still less readily combustible as well as less susceptible to the action of water.

In practice, a bank or battery of twelve to twenty spinning tubes or orifices is operated for each compound filament or thread produced, the single filaments being drawn together in the water, and twisted as they leave it. Practically the sole claim which the product has at present to commercial recognition is found in the surpassing luster of this artificial silk which, as the product is now made, far exceeds that of real silk. Very many superb samples of artificial silk in the form of floss, yarn, braid, cord, as well as dress goods and numerous other fabrics, were seen by me in London this summer, most of these having been produced by the Lehner process. All of this so-called silk has little strength and almost no wearing quality, and what little strength it has is greatly reduced when wet. It takes dyes brilliantly, however, and contrary to the general impression is not more inflammable than cotton, as was proved by many trials. The sole field for the product is in the production of effects; for any other purpose it is merely beautiful rubbish, and its employment evidently requires special skill and knowledge in weaving. It is doubtful if more than twelve or fifteen silk spinners and weavers know, at the present time, how to handle it to obtain the best results. Despite these drawbacks, there is a sustained and insistent demand for all that can be turned out at the present time, at prices ranging from 45 to 50 francs per kilo, which is above the usual price of real silk. The present production of the several plants abroad is about 300 kilos a day, and plants to make about 650 kilos additional, are in course of erection.

A consideration of these artificial silk processes brings us back to viscose, for the reason that the viscose solution has lately been applied upon a large experimental scale at Kew, to the production of artificial silk. The solution has the obvious initial advantages of being much cheaper than the cellulose nitrate solutions, and of yielding a pure cellulose almost at once, thereby doing away with the process of

denitration. The solution is spun through fine capillary tubes into a solution of ammonium chloride, in which the viscose coagulates immediately, although without decomposition. The filaments are then drawn together into the compound thread which is wound up on bobbins after a preliminary twisting. The viscose filaments are thereafter decomposed with recovery of the cellulose by immersing them in boiling brine.

Coming now to the applications which have been made of the recovered cellulose in admixtures with other materials, it should be made clear that when the viscose solution is allowed to decompose spontaneously, the recovered cellulose coagulates into a firm, stiff jelly, from which, as dehydration proceeds, the inorganic by-products are in large part expelled, although a prolonged soaking in water is necessary to remove them all. If, to the viscose solution, inert materials like china clay, powdered coal, graphite, untreated fiber or pigments have been added, these materials become a part of the resulting mass, and modify according to their properties, the character of the product. It is not even necessary, in making such admixtures to bring the viscose into solution, for it is itself plastic and adhesive to about the same extent as a raw rubber dough, so that, after the manner of rubber working, the viscose dough may be admixed with various dilutents, the whole mass remaining plastic. While in this form it may be molded, stamped, squirted into rods or tubes after the manner in which lead pipe is made, or rolled out into sheets, and may even be spun upon a potter's wheel like clay. The articles thus made require to be heated over night to a temperature of about 150° F. to decompose the viscose and recover the cellulose in the form impressed upon the plastic compound. The articles are then dense and hard, but require washing in water to remove alkaline sulpho-carbonates and their by-products.

The extreme facility with which viscose can be admixed with other materials, and the general resemblance of the viscose dough to a crude rubber dough, has led to the working out of methods whereby the viscose and rubber are incorporated together so intimately that upon the subsequent decomposition of the viscose in the vulcanizing process, a film or product is obtained in which the cellulose and rubber seem to actually interpermeate each other. Thus far the application of the new mixture has been almost entirely in the manufacture of waterproof cloth for mackintoshes, although certain other products

such as bicycle tires and other mechanical goods, have been turned out. In the case of mackintosh cloths, the viscose rubber mixture spreads better, and is claimed to give a less porous film than the usual mixtures. The goods can be run faster through the coating machines, and the mixture works more cleanly, but the addition of viscose certainly lowers somewhat the elasticity of the rubber.

The influence of this discovery of Cross, Bevan, and Beadle, upon the general development of the chemistry of cellulose, promises to be perhaps as great as it has already shown itself to be upon the purely technical development of the cellulose industries. The bearing of their discovery upon the chemistry of cellulose, apart from the general stimulus afforded by any great discovery, lies in the fact that the recovered cellulose, especially when sufficiently hydrated to correspond to the formula $C_6 H_{12} O_6$, is far more reactive or susceptible to the action of chemical reagents than any of the ordinary forms of cellulose. It thus becomes possible to prepare easily and in quantities, compounds of cellulose not known before outside the laboratory, and opens up a field for new discovery. The earliest and perhaps the most important of these new commercial products is cellulose acetate, which is now prepared by the method of Cross and Weber, in quantities of several hundred pounds per day.

This method consists, briefly, in mixing the recovered cellulose with magnesium acetate, drying the mixture down, adding small quantities of acetic anhydride with a much larger proportion of acetyl chloride, and stirring the entire mixture until the reaction starts. Carefully regulated quantities of nitrobenzol are then slowly added for the purpose of controlling the reaction and bringing the acetate into solution. The acetate is purified by precipitation in alcohol, and is then washed in water and dried.

The more immediate and obvious uses for cellulose acetate are in the preparation of varnishes and lacquers, photographic films, and sheets to replace celluloid which the acetate closely resembles in appearance and general physical character. It is, however, much less inflammable, and is especially valuable because of its high specific inductive capacity and water-repellant quality.

The greater reactivity of the cellulose recovered from viscose has also been utilized in the preparation of the cellulose nitrates, where also the granular form in which this cellulose is readily obtained offers economics in the acid treatment, and greatly facilitates subsequent washing.

CHARACTER AND EXTENT OF FOOD AND DRUG ADULTERATION IN MASSACHUSETTS, AND THE SYSTEM OF INSPECTION OF THE STATE BOARD OF HEALTH.

By ALBERT E. LEACH.

Read December 28, 1899.

THERE is no more vital question with which we have to deal than that bearing on the quality and purity of our food materials, but it is a matter to which the average man gives but little serious attention, and as a rule the world at large does not concern itself much about what is being done by the government or state in the interests of pure food.

There is a general popular impression that nearly everything we eat or drink is sophisticated in one form or another. Many actually believe that it is a customary practice for grocers to put sand in sugar, and for milk dealers to put chalk in milk, never stopping for a moment to consider that such impossible forms of adulteration as these could not fail to be detected by the most casual observer.

The newspapers are constantly furnishing us with sensational accounts of the terrible extent to which the practice of adulterating food has grown. A statement of this character recently appeared, purporting to have been made by a professor of physiological chemistry in a college outside of New England, to the effect that the alarming growth of food adulteration in this country would, in his opinion, inevitably result in the idiocy of the American people. There is little wonder in the face of such statements as these for the widespread misconception of the true condition of affairs. One reason why people are apt to be misled — and a very natural reason be it said — is, that lacking familiarity with the physical or chemical characteristics of a food, if it does not taste just right, they at once suspect it to be adulterated. They often mistake deterioration for adulteration, or perhaps do not discriminate between goods of an inferior grade and those actually adulterated. As a familiar example of this, we find old or

damaged coffees or spices whose strength or aroma have been lost through exposure to the air frequently though incorrectly deemed adulterated. In like manner a rancid butter is sometimes mistaken for oleomargarine by those who do not know that oleomargarine rarely, if ever, becomes rancid like butter.

Mr. A. J. Wedderburn, special agent for the Department of Agriculture at Washington, who has devoted much attention to the character and extent of food and drug adulteration in this country, estimates the amount of actually adulterated food sold throughout the United States as under 15 per cent. of the whole, and if this is true for the country at large, wherein only six of the states make any special attempt to restrict the sale of impure or adulterated food by prosecution in the courts, it will be apparent that in Massachusetts, where for sixteen years strict laws have been enforced in the matter of food adulteration, a much better state of affairs exists. It would be safe to say that in this state the adulterated food on sale would amount to less than 5 per cent. of the whole. This difference shows at once the beneficial results of the strict enforcement of the food and drug laws in Massachusetts.

In calling attention to the generally exaggerated notion that is prevalent as regards the extent of food adulteration, the writer does not for a moment wish to be understood as in any way belittling the crime of defrauding the people in this way, for it is a crime most certainly, and very properly comes within the jurisdiction of the criminal courts.

The six states which have enacted and are enforcing laws for the suppression of food adulteration are, besides Massachusetts, New York, New Jersey, Ohio, Michigan and Pennsylvania. It is true that most of the states have laws making the sale of adulterated food a misdemeanor, and a few others are beginning to make analyses of articles of food, but excepting in the states mentioned, little if anything is done in the way of executing these laws. Massachusetts is the pioneer in this field, and for many years stood alone in the work. The other states which have swung into line have done so for the most part in comparatively recent years, nearly all having copied our laws in the main, and to some extent our methods. Many of them are doing excellent work, but it is safe to say that Massachusetts is holding her own, as is manifest from the statistics bearing on the quality of her food supply as compared with that of other states.

In 1883 the State Board of Health, or, as it was then called, the Board of Health, Lunacy, and Charity, began the *systematic* inspection of foods and drugs, acting under the authority of the Act of 1882, in accordance with which a sum not exceeding $11,500 per annum was appropriated for the work. The Department of Food and Drug Inspection was then organized, with collectors of samples to purchase various articles of food and drugs for analysis, the chemical part of the work being at that time and for some years thereafter done by various chemists employed to make the analyses in their own private laboratories.

At the outset it is easy to see that the collection of samples had to be done somewhat indiscriminately, not knowing, for instance, at first that certain articles of food were rarely, if ever, subject to adulteration. In 1891 it was thought best to combine under one head the chemical work, an analyst was appointed and in the following year a temporary laboratory for the exclusive work of food and drug inspection was fitted out in the Columbia Theatre Building, pending the completion of the commodious laboratories in the new portion of the State House, which have been the headquarters of the Department for the last five years.

In 1883 less than 1,300 samples were examined. In 1898 over 10,000 samples were collected and analyzed. Of the 1,300 samples analyzed in 1883, 44.5 per cent. were adulterated, and of the samples examined in 1898 the ratio of adulteration was 25.4 per cent.

Figure 1 shows in a general way the variation from year to year in the percentage of adulterated samples of milk, and Figure 2 of foods exclusive of milk through the period covered by the work. The abscissæ are the years from 1883 to 1898, and the ordinates the percentage of adulteration of samples examined in each year. A marked general improvement is shown in the character of the samples. Before explaining the reasons, however, for the fluctuations in the different years, it would be well to briefly outline the method of obtaining samples and review the general routine of the work.

There are three inspectors whose business it is to travel over the state and buy in the open market such foods and drugs as experience has proved most liable to adulteration. For these the regular prices are paid, each sample is numbered as soon as purchased, and all data as to name of dealer, etc., entered in the inspector's book. The duties of the inspector involve more than merely purchasing the goods at

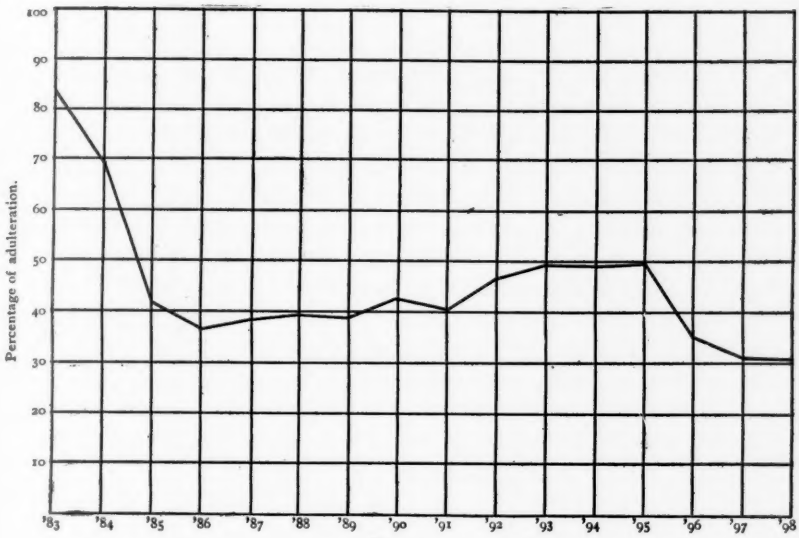

FIG. 1.

Showing the variation in percentage of adulterated samples of milk examined during 16 years.

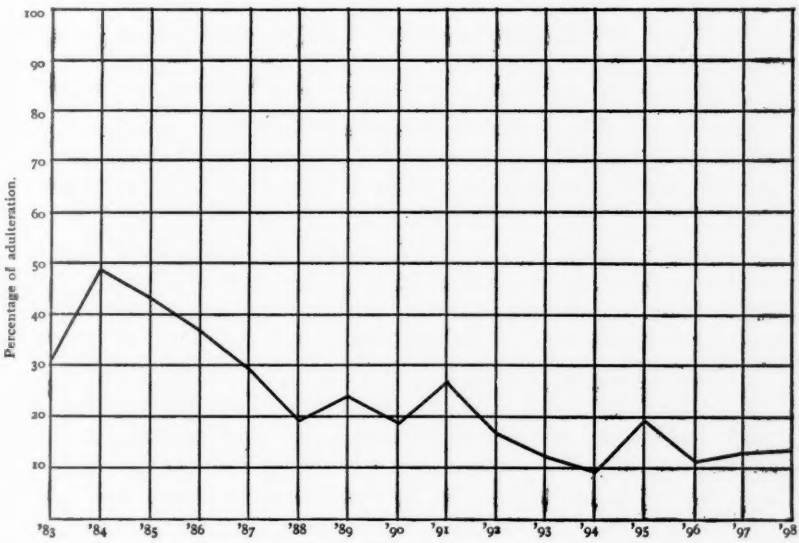

FIG. 2.

Showing the variation in percentage of adulterated samples of milk examined during 16 years.

random. He is supposed to exercise discretion in the singling out of adulterated brands or articles, the cost of an article being in many cases an important factor in determining its liability to adulteration. The inspector, furthermore, soon becomes familiar with the brands that are invariably pure, and seeks to purchase chiefly the suspicious varieties, such as spices sold in bulk rather than in branded packages of well known reliable manufacturers. The samples after being purchased are taken as soon as possible to the laboratory of the Board at the State House and delivered to the analyst either personally, or with such safeguards in respect to lock and key as to leave no question in the courts as to safe delivery and freedom from accidental tampering. The analyst knows nothing of the data of collection, not even knowing the town from which the sample was purchased, so that he can truthfully state in court that his analysis is unbiased. The analyst reports the results of his examination, and the inspector furnishes his data to the secretary of the Board, who puts the two together and determines what shall be done in cases of adulteration. If it is a first offence, or if there are extenuating circumstances of some kind, the offender is probably notified, or if there is good reason for it, he is prosecuted and tried, both the analyst and the inspector being summoned into court to give testimony for the state.

A court case is the almost inevitable result if the adulterated sample has been purchased from a wholesaler or producer, or if, in the case of a retailer, there is good reason to believe the vendor is cognizant of the fact that his goods are poor. While every possible effort is made to trace the goods back in every case to the really responsible party, preferably the manufacturer or at least the wholesaler, it is not always possible to do this for various reasons, it being often found, for example, that the goods were manufactured outside the state. Much good, however, results from the mere notification of the retailer, who can invariably be depended upon to notify in turn the people from whom he bought the goods.

Before beginning an analysis in the case of foods other than milk, the analyst is required to reserve a sample, which, in the event of proving to be adulterated, shall be sealed, and if he is requested to do so, he shall deliver this sample to the defendant that he may have it analyzed by another chemist in his own behalf.

It might perhaps be well to consider at this point just what constitutes an adulterated article of food in the eye of the law. A food

in general is deemed to be adulterated if anything has been mixed with it to reduce or lower its quality or strength; or if anything inferior or cheaper has been substituted wholly or in part therefor; or if any valuable constituent has been abstracted wholly or in part from it; or if it consists wholly or in part of a diseased, decomposed, or putrid animal or vegetable substance; or if it is made to appear of greater value than it really is; or if it contains any added poisonous ingredient.

As to the character of adulteration, nine out of ten, it might almost be said ninety-nine out of a hundred adulterated foods are so classed by reason of the addition of cheaper though harmless ingredients added for commercial profit, rather than by the addition of actually poisonous or injurious substances. As an example of such commercial fraud could be cited the frequent and familiar adding of water to milk, and as an example of the latter or injurious class, the coloring of confectionery with chrome yellow, which is very rarely met with in these days.

Under the law three-fifths of the appropriation is spent for the collection and examination of milk and milk products; hence milk analysis forms a large part of the routine work of the Department. In the year 1898, 6,088 samples of milk were analyzed. Milk is purchased by the inspector from milkmen's wagons, stores, and frequently from the producers on the farm. Milks of known purity are sometimes taken, which were milked in the presence of the inspector. It is our custom to determine the total solids of every sample brought in, and to estimate the fat in such samples only as are below the standard of solids. This standard for total solids as fixed by law is 13 per cent., excepting for the months of April to September inclusive, when it is 12 per cent. The legal standard for total solids in Massachusetts is unusually high. In most European countries the standard is 11.5 per cent., and in no case more than 12 per cent. The ratio of adulteration of milk is largely a question of legislative enactment. The falling off in the percentage of adulteration in the last two years for instance, as shown in Figure 2, is not due to any actual improvement in the quality of the milk of those years, but to the fact that the Legislature in 1897 reduced the standard by 1 per cent. for three additional months.

The percentage of adulteration of milk analyzed by the Department does not by any means indicate the true quality of the milk sold

throughout the State, which is much better than our figures show. This is because the samples brought in for examination are largely taken from suspicious sources, as, for example, from suspected producers. Another cause for the fluctuation of the adulteration of milk in the samples examined from year to year (as evidenced by the eccentricities of the line in Figure 2) is that in some years a large number of milks of known purity have been taken, which would of course bring down the ratio of adulteration perceptibly. This is noticeable in 1886. On the other hand, as in 1893, 1894 and 1895, an unusually large number of milks were brought in from suspected producers, thus causing the percentage of adulteration to run high.

Though watering and skimming are by far the most common forms of milk adulteration, foreign coloring matter is occasionally added, usually to cover up evidences of watering. The coloring matter most commonly employed is annatto. Various coal tar dyes are sometimes found, and very rarely caramel. Though as was said, foreign coloring matter is found for the most part in watered milk, there are instances where it has been found in good rich milk. In one instance an orange diazo-compound of aniline was found in a milk that stood as high as 17 per cent. in solids. About 1 per cent. of the milks examined in 1897 were found to contain added coloring matter.

Addition of any foreign substance whatsoever, as well as having milk below the standard, renders the vendor liable to fine under the law, the minimum fine being $50 for the first offence, $100 for the second offence, and both fine and imprisonment for a third or subsequent offence. Milk cases naturally furnish the larger portion of our court work.

On account of the very efficient character of local milk inspection which Boston as a city possesses, the inspectors of the State Board confine their efforts, so far as milk and milk products are concerned, mainly to collections outside of Boston. It sometimes happens that a Boston milkman is found with poor milk in his wagon, and is brought into court by the local city authorities. It may be that the milk dealer is selling his milk exactly as he receives it, in which case it is often possible for him to prove it. If he can show good reason for it, the case is delayed long enough for the milk dealer to ascertain from the contractor of whom he bought the milk the particular farmer who furnished it. An inspector of the State Board is notified, and he proceeds at once to the producer's farm, which is often far out in the

country, and makes an unexpected early morning call in company with the collector or carrier of the milk to whom the farmer regularly delivers it. The State Inspector takes samples of the producer's milk, and if this is found poor, it is *prima facie* evidence of the city dealer's innocence. The latter is invariably released under such circumstances and the producer prosecuted by the state authorities.

It is by no means true that all milk found below the standard is so by reason of fraudulent or wilful adulteration. There are cows which through poor feeding or otherwise give milk below the legal standard. Then, too, through the carelessness of the milkman in not properly mixing his milk, he may pour off the top of the can which contains the cream, with the result that the remainder is left below the standard.

It has been said that in case of foods other than milk, the analyst reserves a sample of every adulterated food, to be sealed and delivered to the defendant if requested to do so, for purposes of an independent analysis. In the case of milk, however, when an inspector takes a sample from a dealer, the inspector is obliged to give back to the dealer a sealed sample, if requested to do so at the time of the taking.

Various tricks are resorted to by milkmen to avoid being caught with adulterated milk. In one instance an inspector found on a milk wagon, among the regular cans, a suspiciously marked 8-quart can containing what proved to be a mixture of water, salt and caramel. Its obvious purpose was to both water and color at the same time milk given out in small cans from house to house. This method of "doctoring" the milk at the time of its delivery, was a clever dodge on the part of the dealer, in that the milk taken from the wagon was found to be of good quality.

Preservatives of various kinds are now often found in milk. The use of preservatives is on the increase in this country, a stimulus being given to this form of milk adulteration, and indeed to that of many other kinds of food, by the comparatively recent discovery of the remarkable antiseptic power of formaldehyde, so that in the last three years we find it in very general use. The writer has found by experiment that 1 part of formaldehyde in 50,000 parts of milk exerts a very appreciable effect on its keeping qualities, while the addition of 1 part of formaldehyde to 5,000 parts of new milk has kept the sample perfectly sweet for eight days, where a sample of the same milk, un-

treated, curdled at the end of the second day. During the hot summer months a systematic inspection is made of all samples of milk collected for formaldehyde, boracic acid and carbonate of soda, the three most common preservatives. Of 1,500 samples analyzed during July, August and September, 1898, 2½ per cent. contained an added preservative.

The sentiment of physiological chemists is perceptibly changing of late with regard to the use of antiseptics in food, some authorities even going so far as to sanction their use to a limited extent. Many recent experiments in artificial digestion made by Chittenden, Leffmann, and others, on the toxic effects of formaldehyde and other antiseptics, which were considered almost in the light of poisons a few years ago, have tended to show that some of these antiseptics, far from being harmful, may be even helpful in certain of the digestive processes. Much interesting work is being done at the present time along this line. With such encouragement there is little wonder that the use of antiseptics is on the increase, though at present it is an open question how far their use should be allowed in food. In the case of milk, under the present law, it can be stated without reserve that the use of preservatives or *any* foreign substance is illegal, and it is doubtful how far the door could with safety be opened to the even limited use of a foreign substance in milk, no matter if its presence is known to be beneficial in preserving the milk.

Full analyses have been made of all brands of condensed milks and of so-called "evaporated creams" sold in the state, and new brands are being constantly examined as they appear on the market. The condensed milks are very uniformly good, very little of the skimmed variety being found. The worst case of adulteration in this class in recent years was found in the "Dewey Brand" of condensed milk, the label of which contained, besides the portrait of its eminent namesake, a statement to the effect that the contents was made from "the purest milk in Worcester County." This sample was found to contain 0.75 per cent. of fat (having been centrifugally skimmed before condensation), corresponding to a fat in the original milk of 0.25 per cent. The evaporated "creams" are in general condensed whole milks, nothing better, *i.e.*, milk simply condensed without the addition of cane sugar. Rarely we find condensed skimmed milks sold as creams.

As to the milk products butter and cheese, of which a large num-

ber of samples are examined, the ratio of adulteration is very low. The stringent laws regarding the sale of oleomargarine are virtually prohibitory, so that comparatively little oleomargarine is sold in Massachusetts in stores. Occasional small peddlers still venture to evade the law, in spite of the heavy penalty imposed by both the State and the Government for its illegal sale. The former has fixed the fine at $100, and the latter at $1,000. For many years the manufacture and sale of oleomargarine flourished in this state to such an extent that it really furnished a dangerous competitor to the product of the dairy and creamery. Its close resemblance to butter was a source of great temptation to the dishonest dealer, and it was very proper to enact and enforce rigid laws to prevent the fraudulent sale of oleomargarine under the name of butter, which had become at one time a very prevalent practice; but laws of such stringent character were passed as to practically stamp out its sale altogether, for, in accordance with the present law, no oleomargarine can be sold legally in this state which is colored in resemblance to butter, even if it is sold for oleomargarine and so stamped or marked. In other words, to be legally sold it must be white like lard, and experience has shown that no such product will be bought or used. This is on some accounts to be regretted, in view of the fact that oleomargarine has been demonstrated to be a perfectly clean and wholesome food product when properly made, superior in every way to poor butter, and one that can be furnished to people of moderate means at a price considerably below that of the cheapest butter. It is true that the people of Massachusetts can still buy yellow oleomargarine, but they must send outside the state, and have it delivered to them in the original packages.

An industry that seems to be growing in Pennsylvania and other sections of the country more than in New England (though we find the product in our markets), is the manufacture of so-called process or renovated butter. To produce this article old or rancid butter is bought up at a very low price from stores. It is first melted and the clear fat (separated from the curd and foreign materials) is exposed to the air by spraying devices, and while still hot is thoroughly mixed with fresh whole or skimmed milk, after which it is sprayed into ice water, which gives it a granular consistency. This product, while perfectly sweet, lacks the taste of fresh butter, and has very limited keeping qualities. Such butter to be sold legally in this state must be contained in packages plainly marked "Renovated Butter," in letters of prescribed size.

There being in this state no standard for fat in cheese, we almost never find in our markets any of the "filled cheese" so common in the west, as there is no object to the manufacturer in putting in a cheaper foreign fat when he can more readily cheapen his product by skimming his milk. It is to be regretted that we have no law fixing a fat standard for cheese.

In regard to other foods than milk, those most liable to adulteration are found to be in the order named: vinegar, chocolate preparations, honey, olive oil, maple sugar and syrup, spices, coffee, lard, molasses, and cream of tartar.

Vinegar is very commonly adulterated. The law fixes the standard at 2 per cent. of vinegar solids, and $4\frac{1}{2}$ per cent. of acetic acid.

For olive oil is frequently substituted wholly or in part the oil of the cotton seed. Cottonseed oil and beef tallow are the adulterants most commonly found in lard. The refractometer of Zeiss furnishes the most ready preliminary means of detecting adulterants in butter and lard, for which the instrument was originally intended, and we have extended its use to the preliminary examination of olive oils, for which it has been found most reliable.

Coffee offers a ready field to the skilled manipulator, who uses for his materials almost anything he can roast and grind, as peas, pea hulls, chicory, pilot bread, red slate, etc. A common adulterant is a mash of ground, roasted wheat or peas, moulded together with molasses and colored with red ochre. The Department possesses a somewhat rare sample of a very clever counterfeit in point of appearance of the whole coffee beans. They contain no coffee whatever, and consist almost wholly of roasted wheat. They are moulded so neatly as to hardly be distinguishable in outward appearance from the genuine. The microscope is the chief aid in coffee analysis. Figure 3 shows the microscopical appearance of pure coffee. Figure 4 is a photomicrograph of a coffee adulterated with peas and pea hulls. No genuine coffee appears in the field.

Coffee substitutes are, as is well known, very common. It is somewhat amusing to find former makers of adulterated coffees now labelling their goods "coffee substitutes," and calling attention to the very evil effects of coffee itself. Most of these contain cereals only, but one very well advertised brand, purporting to contain nothing but the entire wheat kernel roasted and ground, has also peas and about 30 per cent. of that "most noxious drug," coffee itself.

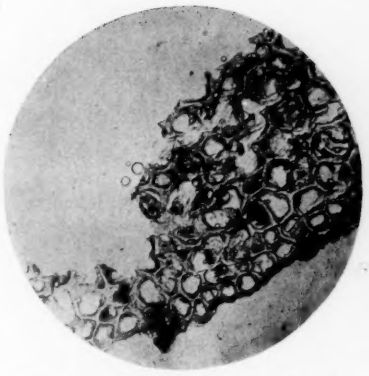

FIG. 3. — GENUINE COFFEE. × 115.

Showing the irregularly hexagonal thick-walled cells enclosing oil drops and amorphous material.

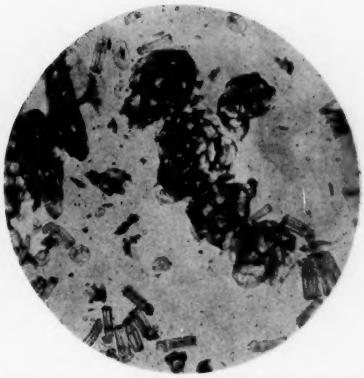

FIG. 4. — COFFEE ADULTERATED WITH ROASTED PEAS AND PEA HULLS. ×115.

No genuine coffee appears in this field. The larger masses are agglomerations of the rounded granules of pea starch, while the rectangular pieces around the edges, sometimes grouped together like bunches of matches, are the cells composing the pea hulls.

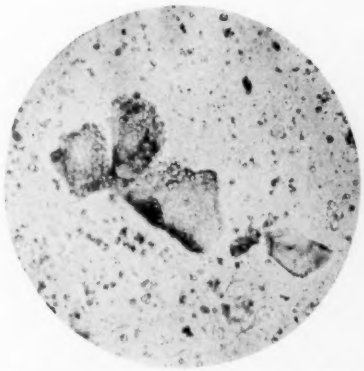

FIG. 5. — ADULTERATED PEPPER. × 115.

The larger masses near the centre of the field are of buckwheat starch while the smaller but similarly shaped mass nearer the margin is of pepper starch, the granules of which are many times smaller than the buckwheat.

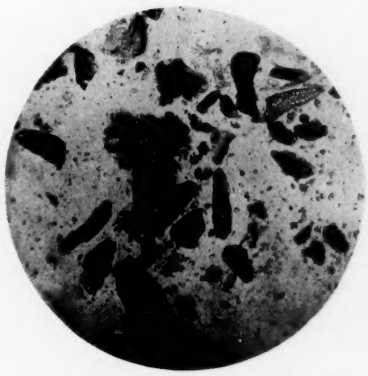

FIG. 6. — CLOVES ADULTERATED WITH GROUND COCOANUT SHELLS. × 115.

A bit of the genuine cloves is shown near the centre of the field consisting of a loose brown granular tissue having oil drops. The long bodies with dark central lines are cocoanut shells.

FIG. 7. — CAYENNE ADULTERATED WITH COCOANUT SHELLS, WHEAT AND CORN. × 115.

The large mass near the margin of the field is a bit of the genuine capsicum skin, the long bodies are the shells, the larger circular starch grains with faint concentric rings are the wheat, and the smaller hexagonal grains the corn.

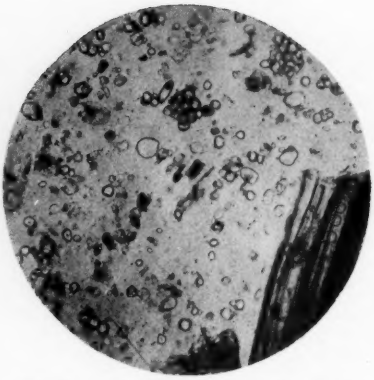

FIG. 8. — GINGER ADULTERATED WITH CORN, WHEAT, TURMERIC AND SAWDUST. × 115.

The starch grains of genuine ginger are oblong with a nubble at one end. The hexagonal cornstarch grains are most numerous in this field. A small bit of turmeric appears at the very edge, adjacent to a mass of soft wood with its long spindle cells and lateral pores.

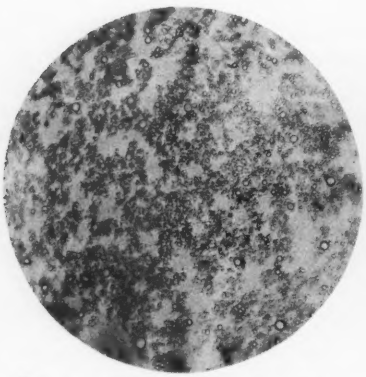

FIG. 9. — GENUINE MUSTARD. × 115.

Showing the ground hulled seed before the extraction of the oil. The free granular masses are the mustard substance; the globular bodies are oil drops.

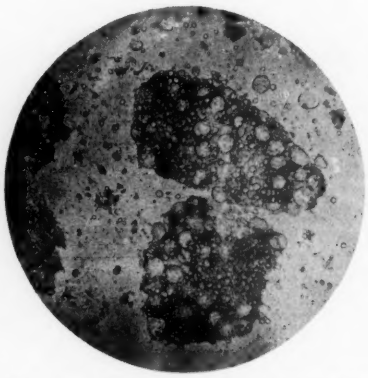

FIG. 10. — MUSTARD ADULTERATED WITH WHEAT. × 115.

From a can of "London Mustard, Extra Strong." Nothing but masses of wheat starch and bran appear in this field.

Tea is very rarely adulterated except by the substitution of inferior grades. This is due to the rigid system of government inspection at the ports of entry.

Perhaps in no class of goods has the really scientific adulteration of food been carried to such an extent as in spices. Here it has become a fine art. Indeed in many cases not only the appearance, but also the taste of the carefully adulterated article are so closely counterfeited as to even tend to deceive the expert. Here, as in the case of coffee, the microscope is the analyst's chief reliance, but where twenty years ago it was only necessary for the dishonest manufacturer to mix anything whatever that could be ground and colored in physical resemblance to the spice in question, now, to keep pace with advanced methods, he frequently seeks out something that resembles the genuine in the *microscopical* appearance as well. As examples of this, there are various inert barks that in some degree resemble the structure of the cassia bark. Sawdust of soft wood is not unlike the wood fiber of the ground ginger root, and buckwheat starch presents an appearance that might possibly be mistaken under the microscope for the starch of pepper to a casual observer. Figure 5 shows these two starches, buckwheat and pepper, in the same field. Naturally these cheap materials are favorite adulterants of the spices in question, but fortunately a careful examination will not fail to detect them. The adulterants of spices are legion. Cassia, cloves and allspice are found to contain as adulterants wheat, corn, ground barks of various kinds, and ground cocoanut shells. Wheat, turmeric, and sawdust are the most common adulterants of mustard and ginger; ground red woods and cornstarch of cayenne, and buckwheat and ground olive stones of pepper. In the case of mace, the most commonly found adulterant is the false, or Bombay mace, sometimes called wild mace. This is a cheap variety, and when ground is utterly devoid of taste and aroma. A spicy taste is often given to mixtures of these inert materials by the addition of a little pepper, cayenne or ginger. Less than 15 per cent. of the spices examined by the Department are adulterated.

Figures 5 to 10 illustrate the microscopical appearance of typically adulterated spices. Figure 11, showing the variation in adulteration of spices, has been inserted because spices furnish the most accurate index of the work of the Department of all foods regularly examined, and constitute a class least subject to variation. Reasons have already

been given to account for the fluctuation of the milk curve in Figure 2. The food curve in Figure 1 also shows some erratic variations, due, among other causes, to the fact that new and different lines of adulterated foods are from time to time discovered, so that one could hardly expect a smooth curve. But the variation in adulteration of spices shows very nearly an even curve, gradually decreasing from 68 per cent. of adulteration in 1883, to nearly a constant level of about 15 per cent. through the last four years.

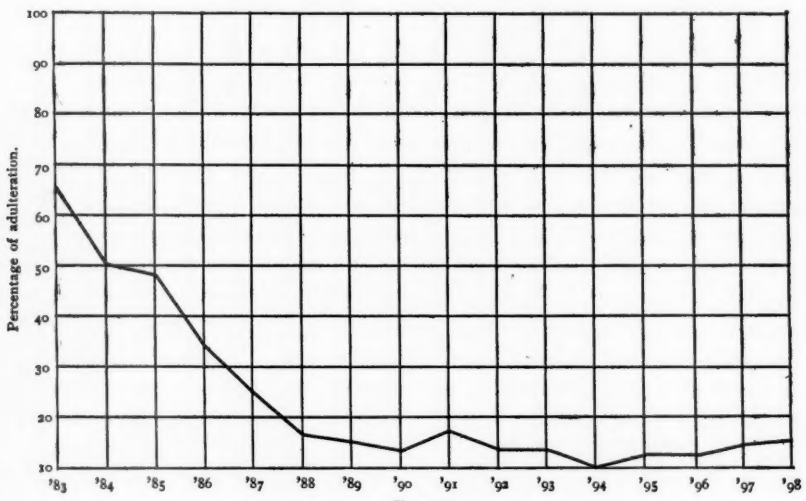

FIG. 11.

Showing the variation in percentage of adulterated samples of spices examined during 16 years.

Until 1897 the dealers in adulterated foods had to some extent protection under the law in that they could legally sell articles of food containing cheaper substitutes, provided the latter were not injurious to health, and provided also that the packages containing them were plainly marked with the word "mixture" or "compound," and sold for such. As might be supposed some of the worst cases of fraudulent adulteration have been practiced under cover of this law. The word "mixture" was seldom used as being too palpable a key to the fact that the goods were adulterated, but to the average buyer the word "compound" conveyed, in a vague sort of way, some form of technical preparation, and did not mean at all the admixture of inferior

ingredients. Often the label read "compounded for family use," or "warranted the best compound." Then, too, all sorts of ingenious labels were devised in which the word "compound" was so indistinctly marked, or so cleverly interwoven into the design of the label as to evade the detection of the average purchaser. Oftentimes the word "pure" appeared in very prominent type on packages of these grossly adulterated foods, while the word "compound" was indistinctly stamped in some obscure corner of the package to purposely evade notice. The law fortunately required the word "compound" to be *distinctly* marked, so that many a fine has been paid in the courts by the evaders of this law. In 1897 the law was changed, so that those who would sell this class of goods legally must have on the label both the names of the ingredients and the percentage as well.

Among this class of compound articles might be mentioned certain brands of jelly, which, while they are claimed by their manufacturers to be properly marked, in that the percentage of ingredients is stated, are yet obvious attempts to deceive, being labelled "Currant Jelly," "Raspberry Jelly," etc., when as a matter of fact there is no currant or raspberry present. The label reads as follows:

Prepared from	
Fruit juice	365
Grape sugar	385
Cane sugar	250
	1,000

The general term "fruit juice" neglects to inform the purchaser that the fruit used is not currant or raspberry, but apple juice, derived from boiling up the cores and parings of canning factories. These jellies are, as a rule, harmless and palatable, and indeed from their cheapness are to be encouraged, but they should be properly marked so as not to masquerade under the names of fruits which they do not contain. Such jellies have, as a rule, only enough cane sugar for sweetening, being chiefly mixtures of apple juice and commercial glucose, colored with an aniline dye.

Molasses, honey, and maple syrup find a ready adulterant in commercial glucose. Its presence and approximate amount is readily determined by the polariscope. The presence of honeycomb is by no means a guaranty of the genuineness of a honey, it being often found in alleged honeys consisting almost wholly of commercial glucose.

There is among the curiosities of the Department a sample sold for honey, which contains not only honeycomb, but also a dead bee. In spite of these evidences of purity, there is no honey at all in the sample, which is a mixture of cane sugar and commercial glucose.

Maple sugar and syrup are also frequently adulterated with cane sugar other than maple, commonly called brown or molasses sugar. Maple syrup sometimes contains an admixture of corn or glucose syrup.

Less than 3 per cent. of the samples of cream of tartar brought in for analysis are adulterated. The adulterants usually employed are gypsum, corn starch and acid phosphate of lime.

Baking powders are considered adulterated if they contain alum, and many of the cheaper brands are found to have it in more or less quantity.

Canned goods are examined for salts of tin and lead. The latter are rarely found to any appreciable extent, because the can is in most cases so constructed as to expose little or no lead to the contents. Tin salts are, however, generally found in the contents of acid fruit and vegetables put up in tin cans. A clue to the quantity of tin dissolved can be had from an examination of the interior of the can, noting the extent of the corrosion. The largest amount of tin found in a single can of fruit was 0.27 grams of SnO_2. This amount was found in a can of blueberries, and the corrosion on the interior of the can was very marked, as shown in Figure 12.

Under the heading of canned goods should be mentioned the new provision of 1899, with regard to canned peas and beans which have been dried and soaked out before canning. It had become quite common, especially in the case of peas, to take those that have become old and dried, and utilize them for canning purposes under some such name as "Choice Early June Peas," such brands being sometimes sold at a very low price. The law now provides that such canned goods to be sold legally, shall have plainly marked on the label of the can the words "Soaked Goods" in letters of a prescribed size. Many brands of such goods are found, however, on the market either not marked at all with the word "soaked," or so illegibly as not to be apparent, and a number of prosecutions have been brought of late on these goods.

Lead is often found in the soft metal disks forming the stoppers of glass jars and bottles in which the cheap carbonated drinks are

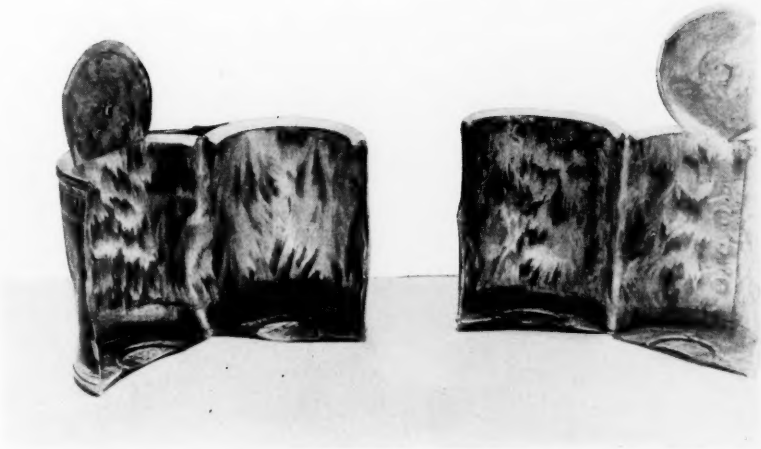

FIG. 12. — BLUEBERRY CANS.

Cut open to show the corrosion of the tin by the fruit acids.

sold, as well as in the wrapping foils of various foods. A cream cheese wrapping foil contained as high as 85 per cent. of lead; 3 per cent. is the danger limit for lead in such wrapping foils as fixed by law in France, and it would be well if a similar law were passed in this state.

French vegetables, as peas, beans, etc., greened by boiling with copper sulphate, are common in our market, but those who wish to sell these goods in accordance with the law mark their cans in such a manner as to indicate the fact. This has been the result of prosecution by the Board.

The miscellaneous foods examined by the Department from time to time are very varied, and space will permit mentioning only a few of the most typical. Canned corn has been found to have been bleached with sulphite of soda. Condiments, as ketchups, sauces, etc., are often found to be preserved with salicylic or benzoic acid. Salt codfish, oysters, and tripe are frequently found to be preserved with boracic acid. Bologna sausages are often colored with aniline dyes (Bismarck brown being a favorite color) and preserved with boracic acid.

The use of preservatives in foods in general is certainly on the increase. A preparation sold under the name of "Preservaline" was a short time ago put on the market. This was sold in neat paper boxes and advertised as "an excellent preservative for keeping cider, vegetables, preserves, jellies, jams, mincemeat, grape juice, etc." On examination it proved to be salicylic acid. According to directions accompanying the sample, three measures of the preservative are to be dissolved in a quart of water, the measure being a small paper cylinder contained in the package. Fruits and berries are to be packed raw in jars or cans, and enough of the "preservaline" solution poured over them to cover them entirely, particular attention being called to the fact that it is not necessary to cook the fruit at all, or even to seal the cans, the sugar for sweetening being added directly to the preserving solution. This solution, made up as directed, is practically a saturated solution of salicylic acid, in which the uncooked fruits and vegetables are soaked till used. In the case of fruits thus preserved that are to be eaten without subsequent cooking, such as berries and the like, wherein the fruit juice mingles with the acid solution, it will be seen that the amount of salicylic acid taken into the system is relatively large.

Vanilla extracts are quite extensively adulterated. Instead of being produced from the essence of the vanilla bean, a large proportion of those on the market, especially of the cheaper brands, owe their flavoring efficiency to coumarin, derived from the Tonka bean.

Cooking utensils have been examined in large numbers for arsenic in the glaze, but with negative results, antimony being quite commonly found, but not arsenic.

Toys are very properly included in our list of suspected articles to be examined, because under the law much could be done to suppress their sale if the coloring matters employed really were injurious. A large number of highly colored imported toys, such as dolls and wooden playthings of various kinds used commonly by very young children, have been examined for arsenic and other poisonous colors, but were found invariably free from anything at all harmful. Lead pigments, as chrome yellow and red lead, are frequently found in iron mechanical toys used by older children, who could hardly be expected to be injured thereby.

As an example of a commercial fraud pure and simple, a so-called egg substitute easily takes the lead. It is called "N' Egg," and is contained in two little boxes, one having a white, the other a yellow powder, being advertised to contain the "nutritive equivalent of the whites and yolks of one dozen fresh eggs, and based on a careful scientific analysis of natural eggs." They are alleged to "differ in composition as do the whites and yolks of eggs." Both powders consist of tapioca starch, this being the sole ingredient of the "whites," while the "yolks" differ from the other only in being colored with Victoria yellow.

Diabetic flour, depending for its therapeutic value on the absence of starch, is a food little used, to be sure, by the people at large, but of all articles this preparation should be what it purports to be, since it is the mainstay of a considerable number of unfortunate people who pay a large price per pound for it. During the present year (1899) thirteen brands of alleged diabetic flour were examined, no less than ten of which (or nearly 80 per cent.) were found to contain starch where none at all should be present. Seven of the ten contained more than 60 per cent. of starch, being in reality nothing better than whole wheat flour, selling at from 30 cents to $1.00 per pound. Many of these brands are put out by dealers in so-called health foods, and some are sold in drug stores.

One of the drug store samples, purporting to be "a pure vegetable gluten" and sold at 50 cents per pound, contained 69 per cent. of starch.

Most of the drugs examined are the pharmacopœial preparations most liable to be below the standard, and include such articles as aqua ammonia, distilled water, chlorinated lime, powdered opium, tincture of opium, tincture of iodine, precipitated sulphur, and many others; also the medicinal liquors sold in drug stores.

A drug is deemed to be adulterated if, when sold by a name recognized by the United States Pharmacopœia, it does not conform to the standard fixed in that work; or when sold by some name not found in the Pharmacopœia, but in some other well recognized book on materia medica, it must conform to the standard laid down in such book. Drugs containing poisonous or injurious substances sold without being properly marked with the poison label, as in the case of corrosive sublimate face washes, formed frequent subjects for prosecutions in court prior to 1897, since which time this class of work has been within the province of the Board of Registration in Pharmacy. It was found unsafe to allow these strong mercurial preparations to go unmarked, even though intended for external use only, by reason of mistakes constantly arising in the hands of ignorant persons, especially as the labels usually stated that the contents of the bottle were harmless. So a law was passed requiring the red poison label with the antidote to be put on the bottle, and this law was at once evaded by putting the poison label on the *bottom* of the bottle where it was rarely seen.

Nearly all the sarsaparilla extracts on the market have been examined for presence or absence of potassium iodide, with the result that some of these preparations claiming to have it were found without it, and *vice versa.* Various proprietary medicines are from time to time examined for injurious ingredients.

A large number of tonics and bitters have been inspected for alcohol, some of them having been highly recommended for temperance drinks. Among these curiosities we find a "purely vegetable tonic, recommended for inebriates," which contained 41.6 per cent. of alcohol; and a certain brand of "Sulphur Bitters" so-called, purporting to contain no alcohol, but which, as a matter of fact, contained 20 per cent. of alcohol and no sulphur. A large number of opium cures have been found to contain morphine in varying amounts.

Various brands of unfermented grape juice are found to contain

large amounts of salicylic acid. Some of them are indeed so loaded with this drug that many physicians, if they knew it, would hesitate before recommending their use. The same is true of some brands of clam bouillon and other invalid preparations.

A certain brand of alleged lime juice, labelled "Santiago West Indian Lime Juice, Triple Refined," on examination proved to be a mixture of hydrochloric and salicylic acids, containing no lime juice whatever.

A rather unpleasant discovery recently made was the amount of arsenic sometimes present in glycerine. During the last few months all the glycerine samples collected have been examined for arsenic, with the result that more than half have been found to contain it. The amount varies from a mere trace to as much as 0.002 gram arsenic in 25 grams of glycerine. The arsenic is present probably as an impurity in the sulphuric acid used in the manufacture of the glycerine.

From the numerous instances of typical adulteration cited, and from figures given both in the case of foods and drugs, an impression might easily be gained that the amount of adulteration is far in excess of what it really is. It will be noticed that as a rule, however, the classes of food mentioned as most liable to adulteration form but a small proportion of the aggregate food supply. The reasons already stated why the character of the milk collected is much worse than that found in the open market, applies also to the other foods and drugs. That is to say, the classes of foods invariably found pure are let alone for the most part, those suspected of being most liable to adulteration being the ones to which attention is chiefly paid. In placing the total amount of adulterated food sold in Massachusetts as under 5 per cent. of the whole, it must be borne in mind that many of the staple articles of food, as for instance sugar, flour, and cereals in general, are rarely found to be adulterated at all.

The photomicrographs accompanying this paper were made by the late Dr. Charles P. Worcester, former analyst of the Board, and have appeared in modified form in Annual Reports of the State Board of Health.

TEMPERATURES AT WHICH CERTAIN FERROUS AND CALCIC SILICATES ARE FORMED IN FUSION, AND THE EFFECT UPON THESE TEMPERATURES OF THE PRESENCE OF CERTAIN METALLIC OXIDES.[1]

By H. O. HOFMAN.

I. Introductory.

In the blast-furnace smelting of lead, copper and other non-ferrous metals, the largest part of the product obtained is slag. Its formation consumes more of the heat energy of the fuel charged than any other chemical reaction that takes place. It is therefore of importance to know at what temperatures the different slags will form, so as to be able to choose in a given case the slag that will form at the right point in the operation, will keep the products thoroughly fluid, so as to insure a satisfactory separation, and will permit the consumption of fuel to be reduced to the lowest practicable point. While practical experience has brought out in a general way the leading differences as to the formation temperatures of some silica-iron-lime slags, accurate details are still wanting. The object of the investigation here described was to supply some of these.[2]

Prominent among the men who have worked on the fusibility of silicates are Lampadius,[3] Sefström,[4] Berthier,[5] Percy-Smith,[6] Bischof,[7] Plattner,[8] Åkerman,[9] Howe,[10] and Gredt.[11]

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[1] Reprinted from Transactions of the American Institute of Mining Engineers, California Meeting, September, 1899.

[2] The expenses of this investigation were defrayed by the American Academy of Arts and Sciences from the income of the C. M. Warren Fund for Chemical Research.

[3] Journal des Mines, 1809, xviii, 171; also Handbuch der Allgemeinen Hüttenkunde, Göttingen, H. Dieterich, 1801–1810, i, 127.

[4] Jernkontorets Annaler, 1828, i, 155; also Erdmann's Journal für Technische und Oekonomische Chemie, 1831, x, 145.

[5] Traité des Essais, Paris, 1834, i, 430.

[6] Percy, Fuel, London, 1875, 59.

[7] Dingler's Polytechnisches Journal, 1862, clxv, 378.

[8] Merbach, Die Anwendung der Erwärmten Gebläseluft in der Metallurgie, Leipsic, 1840, p. 228.

[9] Jernkontorets Annaler, 1886, p. 1; also Stahl und Eisen, 1886, pp. 281, 387; "Graphical Representation," by Howe, Trans. Amer. Inst. of Mining Engineers, xxviii, p. 346.

[10] Trans. Amer. Inst. of Mining Engineers, xviii, 724.

[11] Stahl und Eisen, 1889, ix, p. 759; Åkerman's critique, id., 1800, p. 424.

In the earlier researches, the criterion of fusibility was the time that a mixture or slag was exposed to a heat, or the kind of furnace in which the experiment was carried on. Bischof, in determining the melting points of some silicates of iron, lime, magnesia, and alumina, used the melting points of iron and cast steel for measuring temperatures. Plattner, in working on the formation and melting temperatures of some lead and copper slags, used gold-platinum fusion pyrometers. While his original figures, based upon the calculated melting temperatures of the gold-platinum alloys are very much too high, his results become approximately correct if the melting points of the alloys, as determined by Erhard and Schertel,[1] are substituted. Plattner used clay, iron, and brasqued crucibles, which cannot but have had a decided influence in changing the composition of the mixtures fused in them. Åkerman and Howe employed the calorimetric method in their work on iron blast furnace slags, and Gredt finally made use of Seger cones (of which, more later on) in studying the influence of magnesia upon alumina-lime silicates.

The investigation constituting the subject of this paper was begun in 1895, and continued in 1898. The preliminary work was done by Mr. W. C. Powers, a student in the chemical department of the Institute of Technology, and the final work by Mr. A. L. Davis, first as student in the Department of Mining and Metallurgy of the same institution, and then as the writer's private assistant.

II. Materials.

The slags made in smelting non-ferrous metals in the blast furnace consist mainly of silica, ferrous oxide, and lime, the ferrous oxide being occasionally replaced to some extent by manganous oxide, the lime by magnesia, baryta, and zinc oxide, and the silica and lime by alumina. These compounds, therefore, formed the materials on which the experiments were based.

Silica. — For silica, pure crystallized quartz from Chester, Massachusetts, was chosen. It was ground to pass through a 100-mesh sieve, boiled with nitro-hydrochloric acid until all soluble iron had been removed, and then washed with distilled water until sweet. An analysis gave 99.8 per cent. SiO_2, and the powder was used as if it had been chemically pure.

[1] Freiberger Jahrbuch, 1879, p. 154.

Ferrous Oxide. — Two methods for obtaining the iron in the ferrous state were considered — the decomposition of ferrous oxalate by heating, and the reduction of magnetic oxide by means of metallic iron.

Ferrous oxalate, $FeC_2O_4 + 2H_2O$, is a lemon-yellow powder, formed upon the addition of oxalic acid to a solution of ferrous sulphate, and is an article of commerce. It is stable[1] at an ordinary temperature even when moist. At 150° to 160° C. it gives up one-half of its water. According to Birnie,[2] it gives up all its water below 200° C. when heated in a current of nitrogen, and is completely decomposed at 300° C. The reaction does not, as might be expected, quite correspond to the formula

$$FeC_2O_4 + 2H_2O = FeO + CO + CO_2 + 2H_2O.$$

The black residue of ferrous oxide contains 1 to 1.5 per cent. of carbon, and, as a rule, 0.3 to 2 per cent. of metallic iron; and there are five volumes more of carbon dioxide, and five volumes less of carbon monoxide than the equal volumes called for by the equation. It was believed (and the experiments proved it) that, if the tests were made in a strongly reducing atmosphere, vitreous slags showing no magnetic property whatever could be obtained. As we, however, did not always succeed in producing an absolutely reducing atmosphere in the crucible, many of the slags formed were more or less attracted by the magnet. They were usually black to brown; occasionally they showed a reddish tinge, suggesting a partial oxidation of the iron to the ferric state. The luster on a fresh fracture was vitreous to submetallic.

The second method, which was used by Berthier[3] and Plattner,[4] employs iron scale as the source of iron. The ferrous oxalate was preferred, because it could be obtained as a chemically pure salt, while the analyses of iron scale showed the presence of more or less silica, which would have complicated the calculations. Moreover, there seemed more promise of getting the iron in the ferrous state from a ferrous salt than through the reduction of the magnetic oxide by the use of finely divided metallic iron.

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[1] Ladenburg, Handwörterbuch der Chemie, Breslau, 1890, vol. viii, p. 404.

[2] Receuil des Travaux Chimiques des Pays-Bas, 1883, vol. ii, p. 273; abstract in Jahresberichte über die Fortschritte der Chemie, 1883, p. 1045.

[3] Op. cit., p. 445.

[4] Op. cit., p. 309.

Manganous Oxide, etc. — For manganous oxides, lime, magnesia, and baryta the chemically prepared pure carbonates were used, and for zinc oxide and alumina, the chemically prepared pure oxides.

III. Measurement of Temperature.

As the aim of the investigation was to determine formation temperatures, the calorimetric method used by Åkerman and Howe was excluded, as it gives only the melting points of the formed slags. But even when these are to be determined, the calorimetric method cannot well be used with ferrous slags, owing to the difficulty of finding a suitable crucible material. A clay crucible is attacked by the slag; an iron crucible is liable to increase the percentage of iron; a brasqued crucible causes some iron to be reduced to the metallic state; and, lastly, a platinum crucible[1] when heated in a smoky flame, is damaged through the formation of a carbide of platinum, which, being oxidized by other parts of the flame containing unconsumed air, becomes covered with blister-like excrescences. Again, at a temperature above 1430° C. (Seger cone No. 15) platinum is attacked by the silicates, a silicide of platinum[2] being formed, which is readily fusible. It is not improbable that some iron is reduced to the metallic state and becomes alloyed with the platinum, as the places where the slags have been in contact with the platinum at this high temperature are rough and purplish-red to black; and this change is not superficial, but penetrates the platinum, which becomes very brittle.

The thermo-electric pyrometer of Le Chatelier, which is one of the standards for heat-measurement, was experimented with. The slag mixture was moistened with a solution of dextrine, pressed around the junction in the form of a small ball, and heated slowly after it had been dried. The readings, however, were unsatisfactory, as it was difficult to fix the point at which the deflection of the galvanometer stopped; moreover, particles of the mixture dropped off from the junction; and, lastly, the smoky flame weakened the wires to such an extent that they broke off by their own weight.

[1] See also Roscoe-Schorlemmer, A Treatise on Chemistry, New York, 1880, vol. ii, part ii, p. 399.

[2] Barus, Bulletin No. 54, U. S. Geol. Survey, Washington, 1889, p. 187, and Graham-Otto, Anorganische Chemie, Brunswick, 1889, vol. iv, part ii, p. 1,267.

The second method tried was the employment of Seger cones.[1] It proved satisfactory, and was used throughout the experiments. Seger cones furnish the most valuable means for controlling the temperature of a furnace in which mechanical mixtures are to be converted into chemical compounds by the use of heat. As a complete table of these cones has not yet appeared in the *Transactions*, the latest, as restandardized by Hecht with the Le Chatelier pyrometer, is here given in Table I.

Seger cones have the form of three-sided pyramids. Nos. 022 to 25 are 3 inches high, with a base $\frac{5}{8}$ inch wide,[2] Nos. 26–36 are $\frac{2}{3}\frac{5}{2}$ inch high, with a base $\frac{3}{8}$ inch wide.[3] Each cone has its number stamped on the side, which usually remains uppermost when the cone bends over in melting. The order of numbering is peculiar, and is caused by the way in which the cones were brought out. When Seger found that gold-platinum alloys with over 15 per cent. of platinum showed segregation in melting, and wanted to substitute fusible mixtures used in glazing porcelain, he started with the most fusible one:

$$\left\{\begin{matrix} 0.3\ K_2O \\ 0.7\ CaO \end{matrix}\right\}\ 0.5\ Al_2O_3,\ 4SiO_2.$$

[1] Thonindustrie-Zeitung, 1885, 104, 121; 1886, 135, 145, 168, 229; 1887, 2, 40, 42, 52, 81, 83, 125, 185, 197; 1888, 61, 152, 162; 1889, 102; 1892, 155, 294; 1893, 1,252, 1,281, 1,337, 1,341; 1894, 89, 90, 206; 1895, 73, 88, 117, 803; 1896, 1, 275, 293; 1898, 670, 1,045. The Clay-Worker, 1896, xxv, 261; 1897, xxviii, 111. Trans. American Institute of Mining Engineers, xxiv, 49, 54; xxv, 4, 8; xxviii, 435, 440. *Technology Quarterly*, vi, 301; viii, 63; xi, 255, 261. 18th Annual Report U. S. Geol. Survey, 1897, part v, "Mineral Resources," p. 1,125.

[2] Illustration, see Trans. American Institute of Mining Engineers, xxiv, p. 65, or *Technology Quarterly*, vi, fig. 13, p. 323.

[3] Illustration, see Trans. American Institute of Mining Engineers, xxv, p. 8, or *Technology Quarterly*, viii, fig. 4, p. 68.

TABLE I.—SEGER CONES.

No. of cone.	Composition.			Melting point.	
				°F.	°C.
022	0.5 Na_2O 0.5 PbO	.....	2.0 SiO_2 1.0 B_2O_3	1,094	590
021	0.5 Na_2O 0.5 PbO	0.10 Al_2O_3	2.2 SiO_2 1.0 B_2O_3	1,148	620
020	0.5 Na_2O 0.5 PbO	0.20 Al_2O_3	2.4 SiO_2 1.0 B_2O_3	1,202	650
019	0.5 Na_2O 0.5 PbO	0.30 Al_2O_3	2.6 SiO_2 1.0 B_2O_3	1,256	680
018	0.5 Na_2O 0.5 PbO	0.40 Al_2O_3	2.8 SiO_2 1.0 B_2O_3	1,310	710
017	0.5 Na_2O 0.5 PbO	0.50 Al_2O_3	3.0 SiO_2 1.0 B_2O_3	1,364	740
016	0.5 Na_2O 0.5 PbO	0.55 Al_2O_3	3.1 SiO_2 1.0 B_2O_3	1,418	770
015	0.5 Na_2O 0.5 PbO	0.60 Al_2O_3	3.2 SiO_2 1.0 B_2O_3	1,472	800
014	0.5 Na_2O 0.5 PbO	0.65 Al_2O_3	3.3 SiO_2 1.0 B_2O_3	1,526	830
013	0.5 Na_2O 0.5 PbO	0.70 Al_2O_3	3.4 SiO_2 1.0 B_2O_3	1,580	860
012	0.5 Na_2O 0.5 PbO	0.75 Al_2O_3	3.5 SiO_2 1.0 B_2O_3	1,634	890
011	0.5 Na_2O 0.5 PbO	0.80 Al_2O_3	3.6 SiO_2 1.0 B_2O_3	1,688	920
010	0.3 K_2O 0.7 CaO	0.20 Fe_2O_3 0.30 Al_2O_3	3.50 SiO_2 0.50 B_2O_3	1,742	950
09	0.3 K_2O 0.7 CaO	0.20 Fe_2O_3 0.30 Al_2O_3	3.55 SiO_2 0.45 B_2O_3	1,778	970
08	0.3 K_2O 0.7 CaO	0.20 Fe_2O_3 0.30 Al_2O_3	3.60 SiO_2 0.40 B_2O_3	1,814	990
07	0.3 K_2O 0.7 CaO	0.20 Fe_2O_3 0.30 Al_2O_3	3.65 SiO_2 0.35 B_2O_3	1,850	1,010
06	0.3 K_2O 0.7 CaO	0.20 Fe_2O_3 0.30 Al_2O_3	3.70 SiO_2 0.30 B_2O_3	1,886	1,030
05	0.3 K_2O 0.7 CaO	0.20 Fe_2O_3 0.30 Al_2O_3	3.75 SiO_2 0.25 B_2O_3	1,922	1,050
04	0.3 K_2O 0.7 CaO	0.20 Fe_2O_3 0.30 Al_2O_3	3.80 SiO_2 0.20 B_2O_3	1,958	1,070
03	0.3 K_2O 0.7 CaO	0.20 Fe_2O_3 0.30 Al_2O_3	3.85 SiO_2 0.15 B_2O_3	1,994	1,090
02	0.3 K_2O 0.7 CaO	0.20 Fe_2O_3 0.30 Al_2O_3	3.90 SiO_2 0.10 B_2O_3	2,030	1,110
01	0.3 K_2O 0.7 CaO	0.20 Fe_2O_3 0.30 Al_2O_3	3.95 SiO_2 0.05 B_2O_3	2,066	1,130
1	0.3 K_2O 0.7 CaO	0.20 Fe_2O_3 0.30 Al_2O_3	4 SiO_2	2,102	1,150
2	0.3 K_2O 0.7 CaO	0.10 Fe_2O_3 0.40 Al_2O_3	4 SiO_2	2,138	1,170
3	0.3 K_2O 0.7 CaO	0.05 Fe_2O_3 0.45 Al_2O_3	4 SiO_2	2,174	1,190
4	0.3 K_2O 0.7 CaO	0.5 Al_2O_3	4 SiO_2	2,210	1,210
5	0.3 K_2O 0.7 CaO	0.5 Al_2O_3	5 SiO_2	2,246	1,230
6	0.3 K_2O 0.7 CaO	0.6 Al_2O_3	6 SiO_2	2,282	1,250
7	0.3 K_2O 0.7 CaO	0.7 Al_2O_3	7 SiO_2	2,318	1,270

TABLE I. — SEGER CONES. — *Concluded.*

No. of cone.	Composition.			Melting point.	
				°F.	°C.
8	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$	0.8 Al_2O_3	8 SiO_2	2,354	1,290
9	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$	0.9 Al_2O_3	9 SiO_2	2,390	1,310
10	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$	1.0 Al_2O_3	10 SiO_2	2,426	1,330
11	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$	1.2 Al_2O_3	12 SiO_2	2,462	1,350
12	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$	1.4 Al_2O_3	14 SiO_2	2,498	1,370
13	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$	1.6 Al_2O_3	16 SiO_2	2,534	1,390
14	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$	1.8 Al_2O_3	18 SiO_2	2,570	1,410
15	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$	2.1 Al_2O_3	21 SiO_2	2,606	1,430
16	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$	2.4 Al_2O_3	24 SiO_2	2,642	1,450
17	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$	2.7 Al_2O_3	27 SiO_2	2,678	1,470
18	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$	3.1 Al_2O_3	31 SiO_2	2,714	1,490
19	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$	3.5 Al_2O_3	35 SiO_2	2,750	1,510
20	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$	3.9 Al_2O_3	39 SiO_2	2,786	1,530
21	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$	4.4 Al_2O_3	44 SiO_2	2,822	1,550
22	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$	4.9 Al_2O_3	49 SiO_2	2,858	1,570
23	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$	5.4 Al_2O_3	54 SiO_2	2,894	1,590
24	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$	6.0 Al_2O_3	60 SiO_2	2,930	1,610
25	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$	6.6 Al_2O_3	66 SiO_2	2,966	1,630
26	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$	7.2 Al_2O_3	72 SiO_2	3,002	1,650
27	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$	20 Al_2O_3	200 SiO_2	3,038	1,670
28	.....	1 Al_2O_3	10 SiO_2	3,074	1,690
29	.....	1 Al_2O_3	8 SiO_2	3,110	1,710
30	.....	1 Al_2O_3	6 SiO_2	3,146	1,730
31	.....	1 Al_2O_3	5 SiO_2	3,182	1,750
32	.....	1 Al_2O_3	4 SiO_2	3,218	1,770
33	.....	1 Al_2O_3	3 SiO_2	3,254	1,790
34	.....	1 Al_2O_3	2.5 SiO_2	3,290	1,810
35	.....	1 Al_2O_3	2 SiO_2	3,326	1,830
36	.....	1 Al_2O_3	1.5 SiO_2	3,362	1,850

NOTE. — In 1898, Hecht (Thonind.-Zeit., 1898, p. 670), finding that the difference between Nos. 35 and 36 was rather large, interpolated an additional size, and also began to extend the series beyond No. 36.

He increased its fusibility by a partial substitution of ferric oxide for alumina, and obtained a mixture

$$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\qquad\left\{\begin{matrix}0.3\ Al_2O_3\\0.2\ Fe_2O_3\end{matrix}\right\}4SiO_2$$

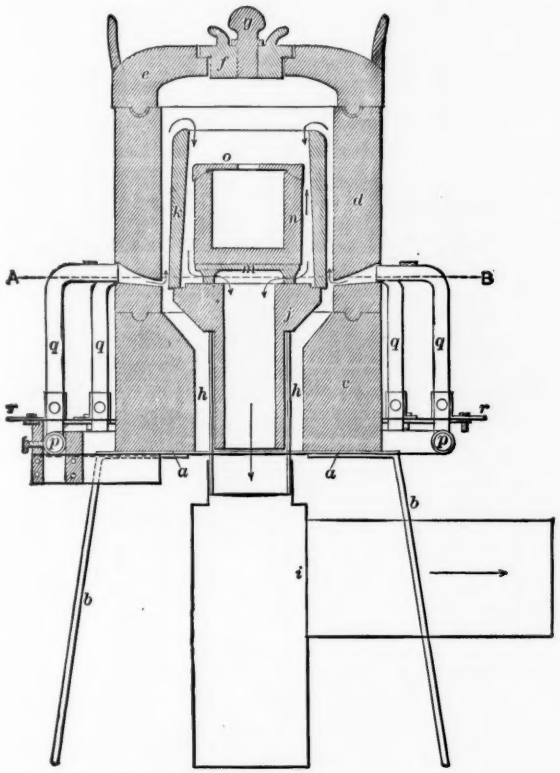
which melted at the same temperature as the alloy Au 90 : Pt 10, or at 1,150° C. This formed No. 1 of his series. He then diminished the fusibility of his mixture, first by increasing the ratio of $Al_2O_3 : Fe_2O_3$, and then by dropping the Fe_2O_3 altogether. After this he increased the ratio of $SiO_2 : Al_2O_3$ until mixture No. 27 was reached, which melted at about 1,670° C. With mixtures Nos. 28 to 36, melting at temperatures ranging from 1,690° to 1,850° C., the bases K_2O and CaO were discarded, and the ratio $Al_2O_3 : SiO_2$ were slowly increased. These mixtures proved so satisfactory that Cramer and Hecht prepared others for lower temperatures, ranging from 1,150° C. to the melting point of silver, 950° C., by replacing part of the SiO_2 with B_2O_3 and numbered them 010 to 01; finally, for mixtures below the melting point of silver down to 590° C., Hecht replaced the CaO by PbO, and the K_2O by Na_2O; he lastly dropped the Fe_2O_3 and decreased the Al_2O_3 and numbered these cones 022 to 011.[1] When several cones are placed in a furnace, the one with the lower number will always melt down before that with the higher number; and the temperature of a furnace corresponds to the cone the tip of which, after bending over, will touch the base. The cones, are however, not true pyrometers; since the change of a mixture into a chemical compound by heating is not a function of temperature alone, but depends also upon the manner of firing, the time given, and the form of the furnace. This has been shown in a very interesting manner by Hecht[2] in firing different batches of porcelain at the Royal Prussian porcelain factory, and controlling the operations by means of Seger cones and the Le Chatelier pyrometer. The temperatures given in the table correspond pretty closely to the control-measurements with the Le Chatelier pyrometer, so long as the heating is carried on slowly. The advantage of using Seger cones in the experiments to be described lies in the fact that the cone, a mechanical mixture, is exposed to

[1] All these cones are imported by Messrs. Eimer & Amend, Third Avenue, New York City, at $3.00 a hundred; Nos. 010 to 20 are furnished at $1.00 a hundred by Professor Edward Orton, Department of Ceramics and Clay Working, Ohio State University, Columbus, Ohio.

[2] Thonindustrie-Zeitung, 1895, p. 803.

accurately the same influences as the slag mixture to be tested; and if this is made up into cones of the same size and form as the Seger, the test leaves little to be desired. The size of the small Seger cone,

FIG. 1.



SEGER GAS FURNACE.
VERTICAL SECTION ON C-D FIG. 2.
Scale, $\frac{1}{8}$ Actual Size.

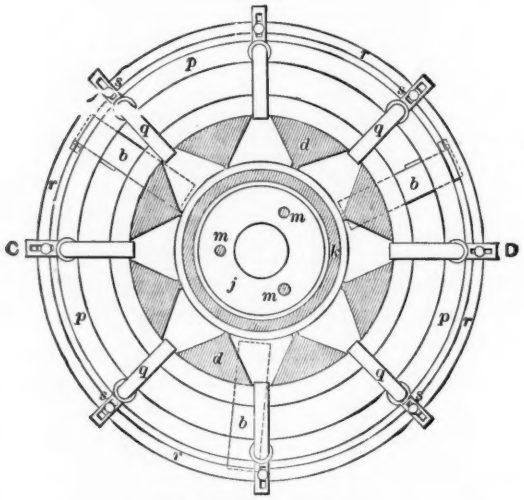
$\frac{25}{32}$ by $\frac{3}{8}$ inch, was chosen for the experiments; and Seger mixture and slag mixture were moulded accordingly.

IV. THE FURNACE.

The furnace used in the experiments was that constructed by Seger for laboratory work in testing low-grade clays, porcelains, glazes, etc. Figures 1 and 2 show vertical and horizontal sections through the fur-

nace. The outer wall, resting on an annular plate *a*, supported by the tripod *b*, consists of two wrought-iron cylindrical jackets *c* and *d*, lined with refractory clay and placed one on top of the other, and a fire-brick cover *e*, with an opening closed by a brick *f*, and a peephole closed by the stopper *g*. The plate *a* supports by means of lugs the heavy wrought-iron pipe *h*, to the lower end of which is attached a stovepipe carrying off the products of combustion into a chimney

FIG. 2.

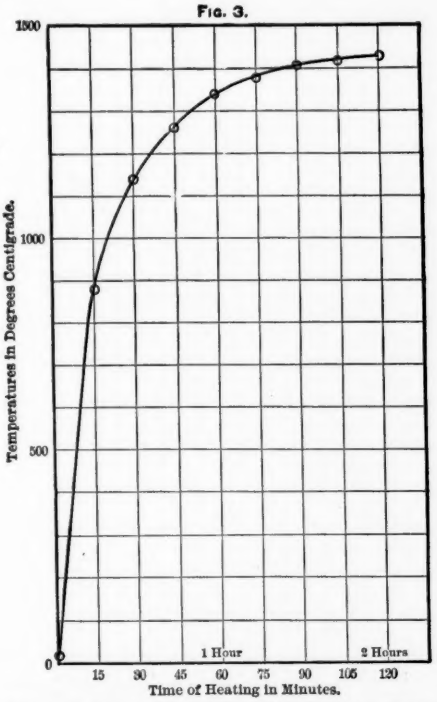


SEGER GAS FURNACE.
HORIZONTAL SECTION ON A-B FIG. 1.
Scale, ⅛ Actual Size.

which must have a strong draught. Into the inside of the upper part fits closely a support of refractory material *j*, which carries the annular fire bridge *k*, and a clay plate with tripod *m* bearing the crucible *n*, with its cover *o*. The furnace is heated with illuminating gas passing from the circular main pipe *p* into eight Bunsen burners *q*. The admission of air to all these is regulated by means of the flat ring *r*, and sliding pins *s*. The flames from the burners ascend between the furnace wall and the fire bridge; are deflected by the roof, and descend between the fire bridge and the crucible; pass underneath the crucible support, and then downward to the pipe which draws off the products of combustion. The furnace can be started quickly or slowly; an

oxidizing or reducing character can be given to the flame; the crucible is uniformly heated, and whatever goes on in it can be observed from without. It is easy to obtain 1,400° C. in the furnace, and by running three hours it is possible to reach 1,600° C. The amount of gas consumed is small, ranging in these experiments from 30 to 150 cubic

FIG. 3.



DIAGRAM, SHOWING THE RATE OF HEATING-UP FURNACE, BURNING 130 CUB. FT. OF GAS PER HOUR.

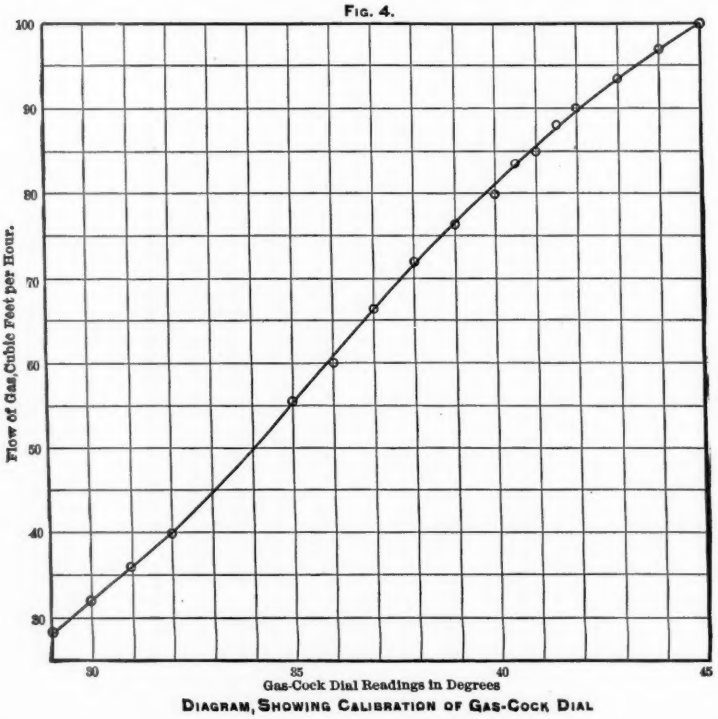
feet per hour. Figure 3 shows the increase of temperature in the crucible, as measured with the Le Chatelier pyrometer, when 130 cubic feet of gas was consumed per hour. The abscissa gives the time in minutes after lighting the furnace; the ordinate, the progressive rise of temperature in degrees Centigrade. To these figures the room temperature, say 20° C. should be added to make the actual temperature.

In order to regulate the admission of gas carefully, a dial clock

was used. The gas from the main passed through a meter, and then through the dial clock into the furnace.

Figure 4 is a diagram in which the abscissa shows the angular reading on the dial, and the ordinate the corresponding quantity of gas that passed through the cock per hour. After having become

FIG. 4.



DIAGRAM, SHOWING CALIBRATION OF GAS-COCK DIAL

familiar with the furnace, we found it possible by turning on a certain flow of gas, to approximate beforehand the time when a certain test would be finished. This is important, because, when more than 75 cubic feet of gas are burned per hour, it is not possible to see down into the crucible. When an observation is to be made, the gas is turned down for a moment to the dial point corresponding to 75 cubic feet per hour. In order to see clearly, smoked glasses are necessary; tints Nos. 2, 4 and 6 proved satisfactory, the darker glass being used for the higher temperature.

In carrying out the large number of experiments recorded below, only two fire bridges and two crucibles, but a considerable number of covers were required. A cover will last only about ten heats. An ordinary 5-inch Battersea roasting dish, with a hole bored in the bottom, makes a good cover.

The lining of the furnace cracked immediately on starting, probably on account of heating up too quickly; but, being held by an iron jacket, it is as good to-day as it was at first, no attempt having been made to fill the crack.

V. Method of Operation.

In preparing the cones of a slag mixture, the ingredients were weighed out and mixed dry in a porcelain dish. They were then moistened on a glass plate, from a wash bottle, with a 10 per cent. solution of dextrine worked with a spatula to a stiff paste and molded into the form of a small-sized ($\frac{3}{8}$ inch base, $\frac{25}{32}$ inch height) Seger cone.[1] As the low-grade Seger cones to be used for the experiments are sold only in large sizes ($\frac{3}{4}$ inch base, $2\frac{3}{8}$ inch height), the loose mixture was procured and molded into the small size as required.

As support for the cones, platinum foil bent into the form of a tray, with one side open, was used. This tray was $1\frac{1}{2}$ inches long, $1\frac{1}{4}$ inches wide, and $\frac{1}{4}$ inch deep. To protect it, a false bottom of scrap platinum was placed in the tray, and on this were set one or two slag cones with several Seger cones. When a fusion was finished, the tray, with the cones adhering to the false bottom, was taken out. The Seger cones usually came off quite easily, as did occasionally also all of the slag cones; but generally some adhering parts could only be removed by treatment with strong hydrochloric acid; and frequently heating in acid potassium sulphate, fused in a clay crucible, was necessary. By the use of the tray with a false bottom, the outlay for platinum consumed in the experiments was reduced to a low figure.

As it was essential to have a reducing atmosphere, a reducing agent that would be readily oxidized was required in the crucible. Oil carbon was chosen. It was cut into segments and fitted into the crucible so as to make a lining 2 or more inches high, and thus completely to surround the test. Oil carbon has practically no ash; in order to prevent the little that it contains from adhering to the bottom

[1] For description of tools, see Trans. Amer. Inst. of Mining Engineers, xxv, pp. 10, 11; or *Technology Quarterly*, viii, 70, 71.

of the crucible, this was covered with a thin layer of pure alumina. As a rule, oil carbon contains some volatile matter which gives a thick smoky flame when the furnace is being started up. It was noticed that this smoky flame reduced the melting points, the difference occasionally reaching 80° C. Since it was impossible to grade the flame, all experiments were made when the crucible had been freed from flame, thus insuring uniform conditions.

In starting the furnace after the crucible had been charged, the openings for admitting air to the Bunsen burners are closed by moving the ring *r*, Figures 1 and 2; the gas-cock is slightly opened, and the gas is ignited. Now the cover is put in place, and a small amount of air is admitted to the burners, until the flame becomes blue. The admission of gas and air is then increased, much more slowly, however, than is shown in Figure 3, which represents a somewhat rapid heating up. It takes from one to three hours to make a test, the time of course, varying inversely with the fusibility of the mixture in the crucible.

While the experiment is going on, the cones must be very carefully watched. As soon as the slag cone is seen to be partly melted, the gas is shut off; the brick in the cover is removed; the furnace is allowed to cool below a dark red; the cover is taken off, then the lid of the crucible is removed; the platinum tray is taken out with cupel-tongs; and another tray, bearing its samples, is put in position and a new test is started. It is absolutely necessary to stop heating as soon as a slag cone is seen to be partially melted; for, if the heating be continued 15 to 30 seconds longer, the cone will have flattened out completely, and will often have become so fluid as to run like water. When a slag cone has thus flattened out, it is hardly possible to compare it with a Seger cone, which always bends over slowly; but at the right moment, just before flattening out, a comparison is easy and accurate. The Seger cone most nearly resembling the slag cone in appearance at that moment is considered to have the same melting point.

The weakness of the method followed in these experiments lies in the fact that the end-point chosen for the slag cone is not fixed, but optional with the experimenter; thus all results given may be too high or too low by 50° C. But an end-point having been settled upon, and the experiments being all carried out by the same person, the results will show very little variation, probably not more than 5° C. Some of the irregularities in the curves, which it would be

unreasonable to attribute to the peculiar behavior of certain silicates, may be explained by a greater or smaller amount of iron present as magnetic oxide instead of ferrous oxide, and thus decreasing the fusibility of the mixture. The fact that a slag mixture will suddenly become fluid when the ingredients have been heated to the point where they unite to form as slag, strongly indicates the generally accepted conclusion, first suggested (it is believed) by Plattner,[1] that the formation temperature of a slag is higher than the melting point of the slag once formed.

VI. Ground Covered by Experiments.

The sub-, singulo-, sesqui-, and bi-silicates, being the ferrous slags commonly made in blast-furnace work, constituted the main subject of investigation. The data necessary for making up the mixtures were taken from the slag table calculated several years ago by Professor R. H. Richards for use in class work. (See Table II.) Although all the figures in this table were not used, it is printed in full because it is new in technical literature, and gives facts of much value for all sorts of slag calculations. It comprises the ferrous slags ranging from the highly basic sub-silicate $5RO, SiO_2$, to the highly acid quadri-silicate $RO, 2SiO_2$. Each silicate series starts with the ferrous silicate, free from calcium oxide, and replaces the ferrous oxide by 4, 8, 12, etc., per cent. of calcium oxide, until a practical limit of the percentage of calcium oxide has been reached.

In the experiments here described:

1. The formation temperatures were determined for the sub-silicates $4RO, SiO_2$ and $3RO, SiO_2$; the singulo-silicate, $2RO, SiO_2$; the three-to-four silicate, $3RO, 2SiO_2$; the sesqui-silicate, $4RO, 3SiO_2$; and the bi-silicate RO, SiO_2, as given in Table II.

2. The formation temperatures were determined for a cross series of slags, starting from the sub-silicate, $4RO, SiO_2$, and extending to the tri-silicate, $2RO, 3SiO_2$; the percentage of ferrous oxide being kept at twice that of calcium oxide, with the purpose of studying the effects of a steadily increasing percentage of silica.

3. A singulo-silicate, in which the percentages of silica, ferrous oxide and calcium oxide were most evenly divided (SiO_2, 32.1; FeO,

[1] Op. cit., p. 333.

TABLE II.—Ferrous and Calcic Silicates Showing Gradations from Highly Basic to Highly Acid Compounds and from all Ferrous to Nearly all Calcic Silicates.

Formulæ of Silicates.	O in bases to O in acids.	Per Cent.													
5RO SiO_2	5 : 2	FeO	85.70	81.55	77.38	73.23	69.05	64.90	60.74	56.57	52.41	48.25	44.10	39.92	35.67	31.60
		CaO	0.	4.	8.	12.	16.	20.	24.	28.	32.	36.	40.	44.	48.	52.
		SiO_2	14.30	14.45	14.62	14.77	14.95	15.10	15.26	15.43	15.60	15.75	15.90	16.08	16.33	16.40
4RO SiO_2	4 : 2	FeO	82.80	78.60	74.40	70.23	66.01	61.81	57.61	53.41	49.22	45.02	40.81	36.61	32.41	28.20
		CaO	0.	4.	8.	12.	16.	20.	24.	28.	32.	36.	40.	44.	48.	52.
		SiO_2	17.20	17.40	17.59	17.77	17.99	18.19	18.39	18.59	18.78	18.98	19.19	19.39	19.59	19.80
3RO SiO_2	3 : 2	FeO	78.30	74.05	69.80	65.51	61.30	57.05	52.80	48.55	44.30	40.06	35.80	31.55	27.52	23.05
		CaO	0.	4.	8.	12.	16.	20.	24.	28	32.	36.	40.	44.	48.	52.
		SiO_2	21.70	21.95	22.20	22.49	22.70	22.95	23.20	23.45	23.70	23.94	24.20	24.45	24.48	24.95
5RO $2SiO_2$	5 : 4	FeO	75.00	70.71	66.43	62.15	57.86	53.57	49.28	45.	40.71	36.43	32.15	27.86	23.50	19.28
		CaO	0.	4.	8.	12.	16.	20.	24.	28.	32.	36.	40.	44.	48.	52.
		SiO_2	25.00	25.28	25.57	25.85	26.14	26.43	26.72	27.	27.29	27.57	27.86	28.14	28.43	28.72
2RO SiO_2	2 : 2	FeO	70.80	66.25	61.91	57.58	53.24	48.90	44.60	40.30	35.90	31.70	27.30	22.90	18.56	14.21
		CaO	0.	4.	8.	12.	16.	20.	24.	28.	32.	36	40.	44.	48.	52.
		SiO_2	29.20	29.75	30.09	30.42	30.76	31.07	31.40	31.70	32.10	32.30	32.70	33.10	33.44	33.79
5RO $3SiO_2$	5 : 6	FeO	66.66	62.26	57.92	53.58	49.24	44.93	40.56	36.22	31.88	27.54	23.20	18.86	14.52	10.10
		CaO	0.	4.	8.	12.	16.	20.	24.	28.	32.	36.	40.	44.	48.	52.
		SiO_2	33.33	33.74	34.08	34.42	34.76	35.07	35.44	35.78	36.12	36.46	36.80	37.14	37.48	37.90
3RO $2SiO_2$	3 : 4	FeO	64.30	60.00	55.60	51.20	46.70	42.25	37.84	33.44	29.04	24.63	20.22	15.80	11.40	6.98
		CaO	0.	4.	8.	12.	16.	20.	24.	28.	32.	36.	40.	44.	48.	52.
		SiO_2	35.70	36.05	36.40	36.80	37.30	37.75	38.16	38.56	38.95	39.37	39.78	40.20	40.60	41.02
4RO $3SiO_2$	4 : 6	FeO	61.54	57.10	52.66	48.22	43.78	39.34	34.89	30.46	26.01	21.58	17.13	12.69	8.26	3.81
		CaO	0.	4.	8.	12.	16.	20.	24.	28.	32.	36.	40.	44.	48.	52.
		SiO_2	38.46	38.90	39.34	39.78	40.22	40.66	41.11	41.54	41.99	42.42	42.87	43.31	43.75	44.19
5RO $4SiO_2$	5 : 8	FeO	60.00	55.54	51.08	46.63	42.17	37.72	33.26	28.80	24.36	19.89	15.43	10.97	6.52	2.06
		CaO	0.	4.	8.	12.	16.	20.	24.	28.	32.	36.	40.	44.	48.	52.
		SiO_2	40.00	40.46	40.92	41.37	41.83	42.28	42.74	43.20	43.64	44.11	44.57	45.03	45.48	45.94
RO SiO_2	1 : 2	FeO	54.55	50.00	45.47	40.96	36.44	31.98	27.43	22.81	18.40	13.89	9.37	4.86	0.35	0.00
		CaO	0.	4.	8.	12.	16.	20.	24.	28.	32.	36.	40.	44.	48.	48.27
		SiO_2	45.45	46.00	46.53	47.04	47.56	48.02	48.57	49.19	49.60	50.11	50.63	51.14	51.65	51.73
4RO $5SiO_2$	4 : 10	FeO	48.98	44.40	39.91	35.23	30.65	26.07	21.49	16.90	12.41	7.74	3.16	0.00		
		CaO	0.	4.	8.	12.	16.	20.	24.	28.	32.	36.	40.	42.75		
		SiO_2	51.02	51.60	52.09	52.77	53.35	53.93	54.51	55.10	55.59	56.26	56.84	57.25		
3RO $4SiO_2$	3 : 8	FeO	47.37	42.76	38.19	33.58	28.98	24.37	19.77	15.16	10.55	5.95	1.35	0.00		
		CaO	0.	4.	8.	12.	16.	20.	24.	28.	32.	36.	40.	41.18		
		SiO_2	52.63	53.24	53.81	54.42	55.02	55.63	56.23	56.84	57.45	58.05	58.65	58.82		
2RO $3SiO_2$	2 : 6	FeO	44.44	39.77	35.14	30.51	25.88	21.24	16.60	11.96	7.32	2.68	0.00			
		CaO	0.	4.	8.	12.	16.	20.	24.	28.	32.	36.	38.36			
		SiO_2	55.55	56.23	56.86	57.49	58.12	58.76	59.40	60.04	60.58	61.32	61.64			
3RO $5SiO_2$	3 : 10	FeO	41.86	37.05	32.41	27.76	23.13	18.47	13.83	9.18	4.53	0.00				
		CaO	0.	4.	8.	12.	16.	20.	24.	28	32.	35.90				
		SiO_2	58.14	58.95	59.59	60.24	60.87	61.53	62.17	62.82	63.47	64.10				
RO $2SiO_2$	1 : 4	FeO	37.50	32.79	28.08	23.37	18.66	13.95	9.24	4.53	0.00					
		CaO	0.	4.	8.	12.	16.	20.	24.	28.	31.82					
		SiO_2	62.50	63.21	63.92	64.63	65.34	66.05	66.76	67.37	68.18					

35.9; CaO, 32.0), was chosen, and the effects of replacing the constituents with manganous oxide, magnesia, baryta, zinc oxide, and alumina were studied.

VII. Record of Results.

In recording the results obtained with the silicate series, a table is given (see Tables III to VIII) for each series of experiments; and the whole is followed by two diagrams (Figures 5 and 6). The tables show the composition of the mixtures in percentages; the percentages of the bases, ferrous and calcium oxide, referred to the sum of their equivalents;[1] the numbers of the Seger cones which fused simultaneously with the mixtures, and the corresponding temperature in degrees C. The two diagrams, Figures 5 and 6, give assembled graphic representations of the tabulated results. The object of calculating and plotting the percentage equivalents, in addition to the percentages by weight, was to show the relative fluxing effects by chemical replacement of ferrous and calcium oxide. Thus, in taking as abscissæ the percentage equivalents of FeO and CaO, it will be seen that for the points *X*, in the curves (III*a*–VIII*a*) where the abscissa is, *e. g.*, 20 per cent. CaO, or 80 per cent. FeO, the SiO_2 is combined with CaO and FeO in the proportion of 1 : 4.

The cross series is represented in Table IX, which gives the composition by weight, the silicate degree, the numbers of the Seger cones, and the corresponding temperatures, and is followed by a diagram (Figure 7).

Tables X to XXI inclusive, represent the replacement of the regular slag constituents in the basal slag, and show how ferrous oxide has been replaced successively by $\frac{1}{8}$, $\frac{2}{8}$, $\frac{3}{8}$ . . . . $\frac{8}{8}$ of its equivalent of manganous oxide; calcium oxide by magnesium, barium, and zinc oxide; and silica, and ferrous and calcium oxide by aluminum oxide.

---

[1] $\frac{\text{Per cent. CaO}}{\text{Mol. w't. CaO}} + \frac{\text{Per cent. FeO}}{\text{Mol. w't. FeO}} = \text{Total, to be reduced to 100.}$

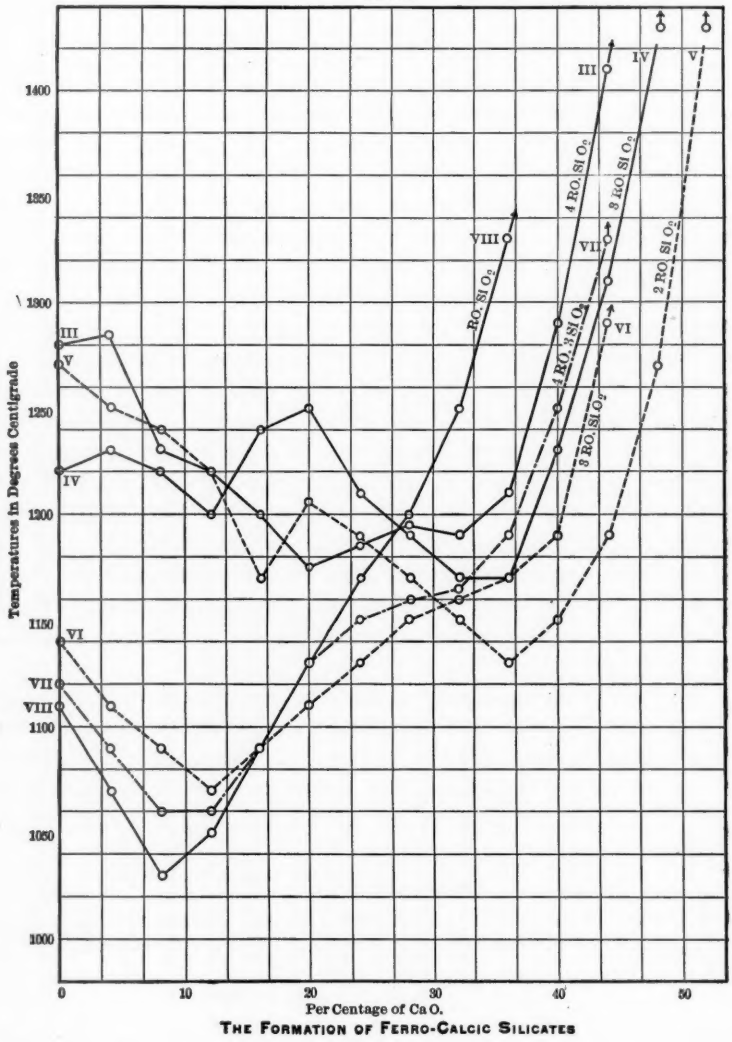
To give an example: In Table V the second slag has the composition SiO_2, 29.75; FeO, 66.25; CaO, 4 per cent. Putting the values for CaO and FeO into the above formula, we have

$$\frac{4}{56} + \frac{66.25}{72} = 0.071 + 0.921 = 0.992.$$

To reduce these figures to percentages, they must be multiplied by 100.8, since $0.992 \times 100.8 = 100$. Thus, $0.071 \times 100.8 = 7.1568$ (given roundly in the table as 7.2); and $0.921 \times 100.8 = 92.83$ (given roundly in the table as 92.80).

Each table gives the numbers of the Seger cones corresponding to the fusions with the degrees C. These tables are followed by three

Fig. 5.

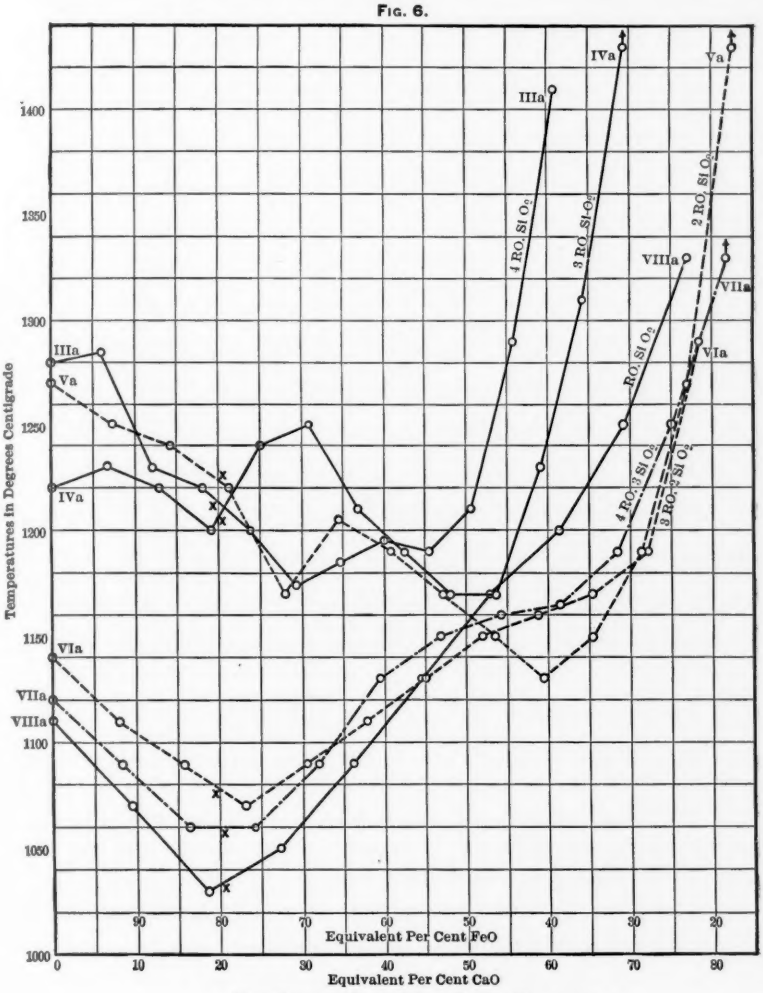


The Formation of Ferro-Calcic Silicates

diagrams (Figures 8 to 10 inclusive), which graphically represent the same results.

Some of the general physical properties of the slags have already been given. Figures 5 and 6 show the temperatures at which the

FIG. 6.

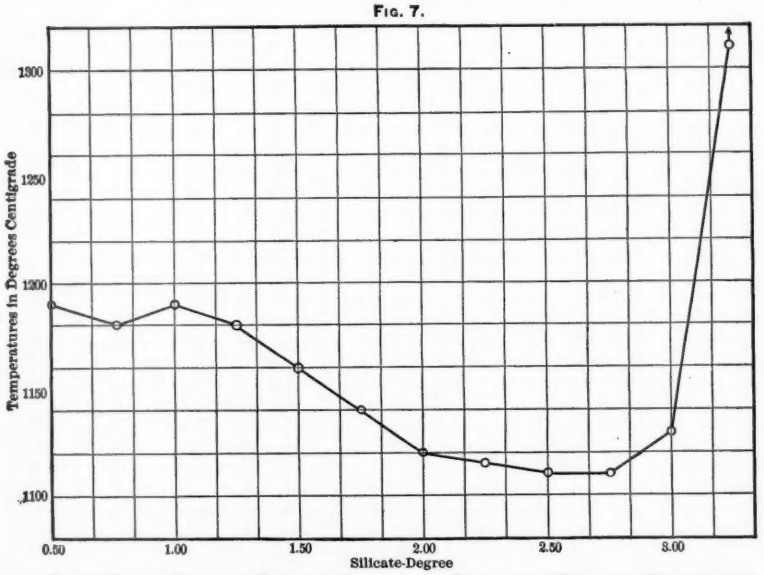


THE FORMATION OF FERRO-CALCIC SILICATES

different slags were formed. In both, the ordinate represents the degrees C.; the abscissa in Figure 5 shows the percentage of calcium oxide in the slags by weight, while in Figure 6 the equivalent percent-

ages of ferrous and calcium oxide based on the sum of the two, are given. As the curves in Figure 6 show the same general character as those of Figure 5, the discussion of temperatures in this paper is based on Figure 5.

FIG. 7.



CROSS-SERIES, SHOWING EFFECT OF INCREASE OF SILICA UPON FORMATION-TEMPERATURE.

The Sub-Silicate, 4RO, SiO_2. (Table III and Figure 5, Curve III.)

The formation temperature of the pure ferrous silicate (SiO_2, 17.20; FeO, 82.80) is 1,280° C. A replacement of FeO oxide by 4 per cent. CaO slightly raises this temperature; but with a further increase of CaO, it falls until the minimum of 1,175° C. is reached with 20 per cent. CaO. A further increase, up to 36 per cent. CaO, slowly raises the formation temperature to 1,210° C., when with still more CaO the curve is seen to ascend rapidly.

TABLE III. — FORMATION OF THE SUB-SILICATE, $4RO, SiO_2$. (See Figures 5 and 6, Curves III and III*a*.)

CHEMICAL COMPOSITION OF SLAG.			EQUIVALENT PER CENT. ON Σ (FeO, CaO).		MELTING POINT.	
SiO_2. Per cent.	FeO. Per cent.	CaO. Per cent.	FeO. Per cent.	CaO. Per cent.	Seger cone No.	Degrees, C.
17.20	82.80	0	100.00	0.00	7½	1,280
17.40	78.60	4	93.86	6.14	7¾	1,285
17.59	74.40	8	87.86	12.14	5	1,230
17.77	70.23	12	81.99	18.01	4½	1,220
17.99	66.01	16	76.25	23.75	3½	1,200
18.19	61.81	20	70.63	29.37	2½	1,175
18.39	57.61	24	65.14	34.86	2¾	1,185
18.59	53.41	28	59.74	40.26	3¼	1,195
18.78	49.22	32	54.49	45.51	3	1,190
18.98	45.02	36	49.31	50.69	4	1,210
19.19	40.81	40	44.25	55.75	8	1,290
19.39	36.61	44	39.29	60.71	14	1,410
19.59	32.41	48	34.46	65.54	15 +	1,430+
19.80	28.20	52	29.69	70.31	15 +	1,430+

The Sub-Silicate, $3RO, SiO_2$. (Table IV and Figure 5, Curve IV.)

The pure ferrous silicate (SiO_2, 21.70; FeO, 78.30), although more siliceous than the preceding one, has a lower formation temperature, viz., 1,220° C. A replacement of FeO by 4 per cent. of CaO slightly raises the temperature, while 8 per cent. of CaO brings it down again to 1,220° C., and the temperature sinks until 12 per cent. CaO is reached, and then, with more CaO, suddenly rises from the first minimum of 1,200° C. to the first maximum of 1,250° C., with 20 per cent. of CaO. With a further increase of CaO, it falls to the second and lowest minimum of 1,170° C., with 32 to 36 per cent. of CaO, and then rises quickly with every small further addition of CaO.

In both the sub-silicates, an addition of 4 per cent. CaO to the pure ferrous silicate causes a rise of the formation temperature, which, upon further addition, soon falls below the starting point. The curves are only 20° C. apart at 12 per cent. CaO; they then diverge, but come together again so as to coincide (1,190° and 1,195° C.) at 28 per cent. CaO; and they reach their lowest points (1,190° and 1,170° C.) at 32 per cent. CaO.

TABLE IV. — FORMATION OF THE SUB-SILICATE, 3RO, SiO_2. (See Figures 5 and 6, Curves IV and IV*a*.)

Chemical Composition of Slag.			Equivalent Per Cent. on Σ (FeO, CaO).		Melting Point.	
SiO_2. Per cent.	FeO. Per cent.	CaO. Per cent.	FeO. Per cent.	CaO. Per cent.	Seger cone No.	Degrees, C.
21.70	78.30	0	100 00	0.00	4½	1,220
21.95	74 05	4	93 51	6.49	5	1,230
22 20	69 08	8	87.17	12.83	4½	1.220
22 49	65.51	12	81.96	18.04	3½	1,200
22 70	61 30	16	74 91	25 09	5½	1.240
22 95	57.05	20	68 97	31.03	6	1.250
23 20	52 80	24	63 15	36 85	4	1.210
23 45	48 55	28	57.45	42 55	3	1,190
23.70	44 30	32	51.91	48.09	2	1.170
23.94	40 06	36	46 46	53.54	2	1,170
24.20	35 80	40	41 08	58 92	5	1,230
24.45	31 55	44	35 85	64.15	9	1.310
24.48	27.52	48	30.69	69.31	15 +	1,430 +
24.95	23.05	52	25.69	74.31	15 +	1,430 +

The Singulo-Silicate, 2RO, SiO_2. (Table V and Figure 5, Curve V.)

The great regularity of this curve is perhaps the explanation of the fact that this slag has become such a favorite in blast-furnace work. The pure ferrous silicate (SiO_2, 29.20; FeO, 70.80) is formed at 1,270° C., and this temperature is uniformly lowered with the replacement of FeO by CaO (excepting a sudden depression between 12 and 20 per cent. CaO), until the minimum of 1,130° C. is reached with 36 per cent. CaO, after which it is raised by further additions of CaO, at first slowly, but then very quickly. The exceptional depression at 16 per cent. CaO was determined by repeated experiments, since it seemed at first that 12 and 20 per cent. CaO ought to have been joined by straight line. The slag resembles closely one of the standard typical lead slags, namely, the one invented by Mr. A. Eilers,[1]

$$6FeO, 3SiO_2 + 2CaO, SiO_2$$

SiO_2, 30.61; FeO, 55.10; CaO., 14.29 per cent.,

which is known to have a very low formation temperature and is used with zincose ores requiring low temperatures and quick smelting.

The curve, after the depression, shows how it is that singulo-silicates high in CaO can be advantageously made in a blast furnace where a comparatively low temperature is to be maintained.

[1] See Hofman, *Lead*, 5th Edition, p. 276.

FIG. 8.

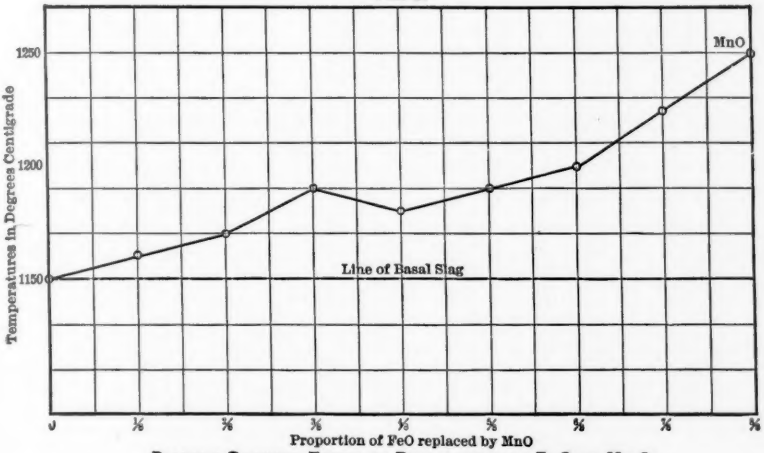


DIAGRAM SHOWING EFFECT OF REPLACEMENT OF FeO BY MnO.

TABLE V. — FORMATION OF THE SINGULO-SILICATE, 2RO, SiO_2. (See Figures 5 and 6. Curves V and V*a*.)

CHEMICAL COMPOSITION OF SLAG.			EQUIVALENT PER CENT. ON Σ (FeO, CaO).		MELTING POINT.	
SiO_2. Per cent.	FeO. Per cent.	CaO. Per cent.	FeO. Per cent.	CaO. Per cent.	Seger cone No.	Degrees, C.
29.20	70.80	0	100.00	0.00	7	1,270
29.75	66.25	4	92.80	7.20	6	1,250
30.09	61.91	8	85.75	14.25	5½	1,240
30.42	57.58	12	78.87	21.13	4½	1,220
30.76	53.24	16	72.12	27.88	2	1,170
31.07	48.90	20	65.55	34.45	3¼	1,205
31.40	44.60	24	59.12	40.88	3	1,190
31.70	40.30	28	52.80	47.20	2	1,170
32.10	35.90	32	46.60	53.40	1	1,150
32.30	31.70	36	40.66	59.34	01	1,130
32.70	27.30	40	34.67	65.33	1	1,150
33.10	22.90	44	28.81	71.19	3	1,190
33.44	18.56	48	23.12	76.88	7	1,270
33.79	14.21	52	17.55	82.45	15 +	1,430 +

The Three-to-Four Silicate, 3RO, 2SiO_2. (Table VI and Figure 5, Curve VI.)

The pure ferrous silicate (SiO_2, 35.70; FeO, 64.30), although running high in SiO_2, is formed at the low temperature of 1,150° C. An addition of CaO, up to 12 per cent., decreases the temperature to

the minimum of 1,070° C. A further increase in CaO raises the formation temperature at first somewhat slowly, but later rapidly, as was the case with the preceding slags.

TABLE VI. — FORMATION OF THE THREE-TO-FOUR SILICATE, $3RO, 2SiO_2$. (See Figures 5 and 6, Curves VI and VI*a*.)

CHEMICAL COMPOSITION OF SLAG.			EQUIVALENT PER CENT. ON Σ (FeO, CaO).		MELTING POINT.	
SiO_2. Per cent.	FeO. Per cent.	CaO. Per cent.	FeO. Per cent.	CaO. Per cent.	Seger cone No.	Degrees, C.
35.70	64.30	0	100.00	0.00	$01\frac{1}{2}$	1,140
36.05	60.00	4	92.10	7.90	02	1,110
36.40	55.60	8	84.39	15.61	03	1,090
36.80	51.20	12	76.85	23.15	04	1,070
37.30	46.70	16	69.42	30.58	03	1,090
37.75	42.25	20	62.17	37.83	02	1,110
38.16	37.84	24	55.07	44.93	01	1,130
38.56	33.44	28	48.17	51.83	1	1,150
38.95	29.04	32	41.40	58.60	$1\frac{1}{2}$	1,160
39.37	24.63	36	34.75	65.25	2	1,170
39.78	20.22	40	28.92	71.78	3	1,190
40.20	15.80	44	21.83	78.16	8	1,290
40.60	11.40	48	15.63	84.37	15+	1,430
41.02	6.98	52	9.46	90.54	.....	.....

The Sesqui-Silicate, $4RO, 3SiO_2$. (Table VII and Figure 5, Curve VII.)

The formation temperature of the pure ferrous silicate (SiO_2, 38.46; FeO, 61.54) is 1,120° C., or 20° lower than that of the preceding, less siliceous, three-to-four silicate. It reaches its minimum at 1,060° C., when 8 to 12 parts of CaO have replaced equivalent amounts of FeO. It then rises again, intersects the three-to-four and the bi-silicate curves with 16 per cent. CaO, coincides with the bi-silicate curve at 16 to 20 per cent. CaO, and finally rises with a further increase of CaO, but more slowly than does the bi-silicate curve.

FIG. 9.

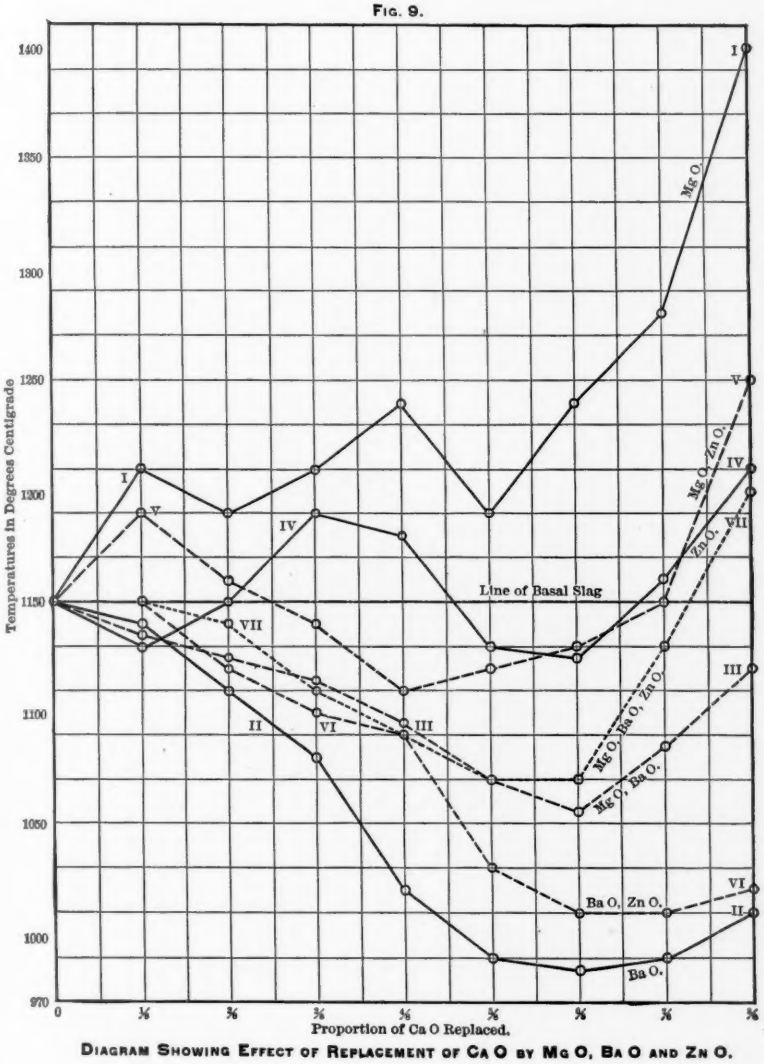


DIAGRAM SHOWING EFFECT OF REPLACEMENT OF CA O BY MG O, BA O AND ZN O.

TABLE VII. — FORMATION OF THE SEQUI-SILICATE, $4RO, 3SiO_2$. (See Figures 5 and 6, Curves VII and VII*a*.)

CHEMICAL COMPOSITION OF SLAG.			EQUIVALENT PER CENT. ON Σ (FeO, CaO).		MELTING POINT.	
SiO_2. Per cent.	FeO. Per cent.	CaO. Per cent.	FeO. Per cent.	CaO. Per cent.	Seger cone No.	Degrees, C.
38.46	61.54	0	100.00	0.00	$02\frac{1}{2}$	1,120
38 90	57.10	4	91.74	8.26	03	1.090
39.34	52 66	8	83.66	16.34	$05\frac{1}{2}$	1,060
39.78	48 22	12	75.76	24.24	$05\frac{1}{2}$	1,060
40 22	43.78	16	68.03	31.97	03	1,090
40.66	39.34	20	60.48	39.52	01	1,130
41.11	34.89	24	53.07	46 93	1	1,150
41.54	30.86	28	45 82	54 18	$1\frac{1}{2}$	1,160
41.99	26 01	32	38 73	61.27	$1\frac{1}{2}$	1,165
42.42	21.58	36	31.79	68 21	3	1,190
42.87	17 13	40	24 98	75 02	6	1,250
43 31	12.69	44	18.26	81 74	11 +	1,330 +
43.75	8 26	48	11.65	88.35	.....	.....
44.19	3.81	52	.....	.....	.....	.....

The Bi-Silicate, RO, SiO_2. (Table VIII, and Figure 5, Curve VIII.)

The formation temperature of the pure ferrous silicate (SiO_2, 45.45; FeO, 54.55), the most siliceous that is made in blast-furnace work, is 1,110° C., being lower than that of any of the other slags. The addition of CaO up to 8 per cent. brings it down to a minimum of 1,030° C.; but with more CaO the curve is reversed and quickly ascends in the temperature scale. While a bi-silicate slag is rarely made at present, it was a favorite slag in former years, when little if any lime was added to the ore charge. The curve shows the low formation temperatures of slags containing under 10 per cent. of CaO.

The acid character of these slags prevented them from attacking the acid furnace material enclosing the smelting zone, but their fluidity was small; they ran very slowly from the furnace, and thus they were the cause of the small number of charges that could be put through, while they also obstructed the settling out of the valuable products

In comparing the different slags, it will be seen that the pure ferrous silicates always have the highest formation temperatures; that a replacement of FeO by CaO reduces these temperatures to certain points, but that with further additions of CaO the curves are reversed, and the formation of silicates takes place at rapidly increasing temperatures. The curves do not show, as was hoped, any simple connec-

TABLE VIII. — FORMATION OF THE BI-SILICATE, RO, SiO_2. (See Figures 5 and 6, Curves VIII and VIII*a*.)

CHEMICAL COMPOSITION OF SLAG.			EQUIVALENT PER CENT. ON Σ (FeO, CaO).		MELTING POINT.	
SiO_2. Per cent.	FeO. Per cent.	CaO. Per cent.	FeO. Per cent.	CaO. Per cent.	Seger cone No.	Degrees, C.
45.45	54.55	0	100.00	0.00	02	1,110
46.00	50.00	4	90.67	9.33	04	1,070
46.53	45.47	8	81.55	18 45	06	1,030
47.04	40.96	12	72.65	27.35	05	1,050
47.56	36.44	16	63.87	36.13	03	1,090'
48.02	31.98	20	55.45	44.55	01	1,130
48.57	27.43	24	47.09	52.91	2	1,170
49.19	22.81	28	38.80	61.20	3	1,200
49 60	18.40	32	30.92	69.08	6	1,250
50.11	13.89	36	23.09	76.91	10	1,330
50.63	9.37	40	15.41	84.59	15 +	1,430
51.14	4.86	44	7.90	92 10	.....	.....
51.65	0.35	48	0.58	99.42	.....	.....
51.73	0.00	48.27	0.00	100.00	.....	.....

tion between silicate degree, percentage of lime, and minimum of formation temperature.

The Cross Series. (Table IX and Figure 7.)

For the cross series designed to show the effect of an increase of silica on the formation temperature, a slag was chosen in which the ratio of FeO : CaO was 2 : 1, as in Table IX, which gives the chemical composition; the silicate degree, from O basic : O acid = 2 : 1 to O basic : O acid = 1 : 3.25 increasing in steps of 0.25; the numbers of the Seger cones at which the fusions took place; and the corresponding temperature in degrees C.

The slags at the basic end are very fluid as soon as the formation temperature has been reached, and are noticeably attracted by the magnet, while those at the extreme acid end fuse down slowly, carry uncombined silica, and are but slightly magnetic.

Figure 7 represents graphically the results of the tests. It shows that from the silicate degree 0.5 to 1.25 the formation temperatures show only a difference of 10° C. (between 1,180° and 1,190° C.); then they fall, at first more rapidly than afterward, until the minimum of 1,110° C. is reached with a silicate degree of 2.50 to 2.75; then they rise quickly to 1,130° C. with the tri-silicate, and, at last, abruptly ascend the temperature scale.

TABLE IX. — FORMATION OF SLAGS IN WHICH THE RATIO FeO : CaO = 2:1.

CHEMICAL COMPOSITION OF SLAG.			Silicate, degree.	MELTING POINT.	
SiO_2. Per cent.	FeO. Per cent.	CaO. Per cent.		Seger Cone. No.	Degrees. C.
18.67	54.23	27.10	0.50	3	1,190
25.61	49.60	24.79	0.75	$2\frac{1}{2}$	1,180
31.47	45.68	22.85	1.00	3	1,190
36.47	42.36	21.17	1.25	$2\frac{1}{2}$	1,180
40.80	39.46	19.74	1.50	$1\frac{1}{2}$	1,160
44.55	36.97	18.48	1.75	$01\frac{1}{2}$	1,140
47.86	34.77	17.37	2.00	$02\frac{1}{2}$	1,120
50.82	32.78	16.40	2.25	$02\frac{1}{2}$	1,115
53.44	31.04	15.52	2.50	02	1,110
55.81	29.46	14.73	2.75	02	1,110
57.95	28.04	14.01	3.00	01	1,130
59.87	26.75	13.38	3.25	9+	1,310+

While low formation temperatures are desirable as reducing the amount of fuel required, a slag of a silicate degree of 2.50 to 2.75 is too viscid to flow freely. Hence, slags less siliceous and more fluid are usually made, even if the temperatures at which they are formed are higher. Thus the singulo-silicate slag SiO_2, 31.47; FeO, 45.68; CaO, 22.85 per cent., corresponding to the formula

$$6FeO,\ 3SiO_2,\ +\ 4CaO,\ 2SiO_2,$$

which is the one first made by A. Eilers,[1] and is one of the best slags for smelting lead ores in the blast furnace.

Replacement of Slag Constituents.

For the study of the effect of some of the metallic oxides which replace silica, ferrous oxide, and calcium oxide in a blast furnace slag, a singulo-silicate was chosen, as this is the leading slag made in smelting non-ferrous metals. Of the fourteen singulo-silicates given in Table II, the one containing SiO_2, 32.10; FeO, 35.90; CaO, 32.00, was selected, because the three constituents being about equally divided, the largest range of experiment was afforded, and also because the formation temperature, 1,150° C., was low.

In Table X it will be seen that $\frac{1}{8}$ of a constituent has been every time replaced by an equivalent weight of one or more metallic oxides, until the latter had wholly taken the place of the original constituent.

[1] See Hofman, *Lead*, 5th Edition, p. 276.

In Figures 8 to 10, inclusive, the original slag, called basal slag, is represented by a horizontal line corresponding to its formation temperature of 1,150° C.

1. *Replacement of FeO by MnO.* — Table X gives the weight of the charges with numbers of the Seger cones and corresponding temperatures at which the slags were formed.

FIG. 10.

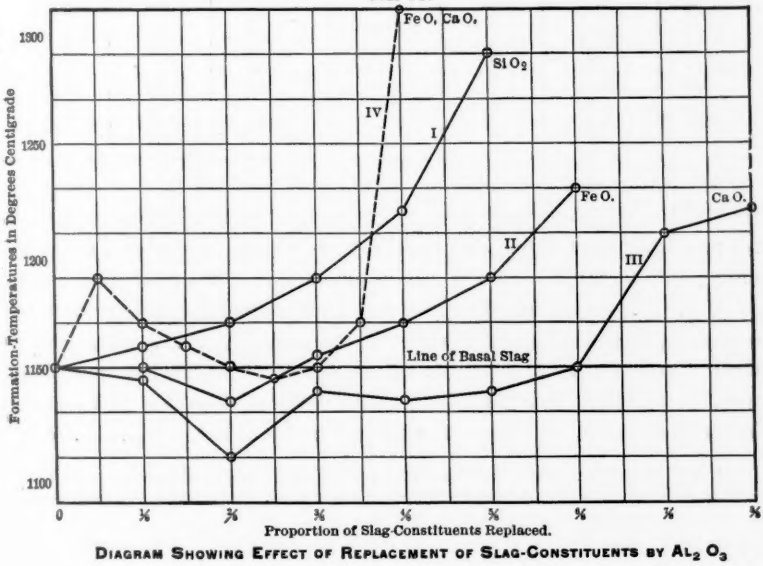


DIAGRAM SHOWING EFFECT OF REPLACEMENT OF SLAG-CONSTITUENTS BY $Al_2 O_3$

All these slags were watery; ranged in color from dark-gray to black (on the surface frequently dark-brown); showed a dull to slightly vitreous luster, and were noticeably attracted by the magnet.

The effect of MnO on the formation temperature is clearly seen in Figure 8. Manganese replacing iron raises this temperature approximately in proportion to the degree of replacement. It is usually said that manganese makes a slag more fusible, as well as more fluid; but these experiments show that the first statement will have to be reversed.

TABLE X.

Chemical Composition of Slag, in Grams.					Melting Point.	
SiO_2.	FeO.		MnO.	CaO.		
	Remaining.	Replaced.	Replacing.		Seger cone. No.	Degrees. C.
32.10	35.90	....	.....	32.00	1	1 150
32.10	31 41	$\frac{1}{8}$	4.424	32.00	$1\frac{1}{2}$	1.160
32.10	26 93	$\frac{2}{8}$	8 847	32.00	2	1.170
32 10	22 44	$\frac{3}{8}$	13 27	32 00	3	1.190
32 10	17 95	$\frac{4}{8}$	17 69	32 00	$2\frac{1}{2}$	1,180
32 10	13.46	$\frac{5}{8}$	22 12	32.00	3	1.190
32.10	8 975	$\frac{6}{8}$	26 54	32 00	$3\frac{1}{2}$	1,200
32.10	4.487	$\frac{7}{8}$	30 97	32.00	$4\frac{1}{2}$	1.225
32.10	0.00	$\frac{8}{8}$	35.39	32.00	6	1,250

2. *Replacement of CaO by MgO, BaO and ZnO.* — Tables XI to XVII, inclusive, give the charges used in making up the mixtures for replacing the CaO of the basal slag by MgO, BaO and ZnO, severally and together. In the same manner as with FeO and MnO, $\frac{1}{8}$, $\frac{2}{8}$, $\frac{3}{8}$, . . . etc., of the CaO has been replaced by the metallic oxides, giving to the mixtures 32, 28, 24, 22, . . . etc., grams CaO, the other 4, 8, 12, etc., grams being replaced by equivalent weights of MgO, BaO and ZnO, respectively (Tables XI, XII, XIV). Where two metallic oxides take the place of CaO, 2, 4, 6, . . . etc.,

TABLE XI. — The Effect of Replacing CaO with MgO. (Figure 9, Curve 1.)

Chemical Composition of Slag, in Grams.					Melting Point.	
SiO_2.	FeO.	CaO.		MgO.		
		Remaining.	Replaced.	Replacing.	Seger cone. No.	Degrees. C.
32 10	35.90	32	....	0 00	1	1,150
32 10	35 90	28	$\frac{1}{8}$	2 874	4	1,210
32 10	35 90	24	$\frac{2}{8}$	5 748	3	1,190
32 10	35.90	20	$\frac{3}{8}$	8 622	4	1.210
32 10	35.90	16	$\frac{4}{8}$	11.49	$5\frac{1}{2}$	1,240
32 10	35.90	12	$\frac{5}{8}$	14.37	3	1,190
32 10	35.90	8	$\frac{6}{8}$	17.24	$5\frac{1}{2}$	1,240
32.10	35 90	4	$\frac{7}{8}$	20.12	$7\frac{1}{2}$	1.280
32.10	35 90	....	$\frac{8}{8}$	22 99	$13\frac{1}{2}$	1,400

None of the slags appear to be very fluid. They are all opaque. On the fracture they are grayish-black, the gray increasing with the MgO to such an extent as to make the last three slags a silvery-gray. The surface shows throughout a brownish tone; the luster is vitreous; all the slags are attracted by the magnet, those rich in MgO less so than those having a high percentage of CaO.

grams are exchanged for the equivalent weight of the one, and the remaining 2, 4, 6 . . . grams for that of the other (Tables XIII, XV, XVI). With three substituting oxides, each replaces $\frac{1}{3}$ of the grams of CaO that are to be taken out (Table XVII).

Figure 9 represents graphically the results given in the tables.

TABLE XII. — THE EFFECT OF REPLACING CaO WITH BaO. (Figure 9, Curve II.)

Chemical Composition of Slag, in Grams.					Melting Point.	
SiO_2.	FeO.	CaO.		BaO.		
		Remaining.	Replaced.	Replacing.	Seger cone. No.	Degrees. C.
32.10	35.90	32	...	0.00	1	1,150
32.10	35.90	28	$\frac{1}{8}$	10.94	$01\frac{1}{2}$	1,140
32.10	35.90	24	$\frac{2}{8}$	21.88	02	1,110
32.10	35.90	20	$\frac{3}{8}$	32.83	$04\frac{1}{2}$	1,080
32.10	35.90	16	$\frac{4}{8}$	43.77	$07\frac{1}{2}$	1,020
32.10	35.90	12	$\frac{5}{8}$	54.72	08	990
32.10	35.90	8	$\frac{6}{8}$	65.66	$09\frac{1}{4}$	985
32.10	35.90	4	$\frac{7}{8}$	76.60	08	990
32.10	35.90	...	$\frac{8}{8}$	87.54	07	1,010

The slags were opaque and not very fluid. On the fracture the color is steel-gray to black; on the surface somewhat brownish. The luster is vitreous. The slags toward the end of the series are more attracted by the magnet than those at the beginning. With slags melting below 1,080° C., the carbon dioxide of the barium carbonate had not all been driven off when fusion had begun.

TABLE XIII. — THE EFFECT OF REPLACING CaO WITH MgO AND BaO. (Figure 9, Curve III.)

Composition of Slag in Grams.						Melting Point.	
SiO_2.	FeO.	CaO.		MgO.	BaO.		
		Remaining.	Replaced.	Replacing.	Replacing.	Seger cone. No.	Degrees. C.
32.10	35.90	32	...	0.00	0.00	1	1,150
32.10	35.90	28	$\frac{1}{8}$	1.436	5.471	$01\frac{1}{2}$	1,135
32.10	35.90	24	$\frac{2}{8}$	2.874	10.94	$02\frac{1}{2}$	1,125
32.10	35.90	20	$\frac{3}{8}$	4.310	16.41	$02\frac{1}{2}$	1,115
32.10	35.90	16	$\frac{4}{8}$	5.748	21.88	$03\frac{1}{2}$	1,095
32.10	35.90	12	$\frac{5}{8}$	7.184	27.35	04	1,070
32.10	35.90	8	$\frac{6}{8}$	8.622	32.83	$05\frac{1}{2}$	1,055
32.10	35.90	4	$\frac{7}{8}$	10.06	38.30	$04\frac{1}{2}$	1,085
32.10	35.90	...	$\frac{8}{8}$	11.49	43.77	$02\frac{1}{2}$	1,120

The slags were opaque, and did not appear to flow well. On the fracture the color at the beginning of the series was a dark steel-gray and changed to black toward the end; on the surface it was brownish. The luster was only slightly vitreous, and the slags were magnetic throughout. Slags melting below 1,085° C. began to fuse before all the carbon dioxide of the barium carbonate had been driven off.

TABLE XIV.—The Effect of Replacing CaO with ZnO. (Figure 9, Curve IV.)

Composition of Slag, in Grams.					Melting Point.	
SiO_2.	FeO.	CaO.		ZnO.		
		Remaining.	Replaced.	Replacing.	Seger cone. No.	Degrees. C.
32 10	35 90	32	...	0 000	1	1,150
32 10	35 90	28	$\frac{1}{8}$	5 806	01	1,130
32 10	35.90	24	$\frac{2}{8}$	11 61	1	1,150
32 10	35 90	20	$\frac{3}{8}$	17 42	3	1.190
32 10	35 90	16	$\frac{4}{8}$	23 22	$2\frac{1}{2}$	1,180
32 10	35 90	12	$\frac{5}{8}$	29 03	01	1,130
32 10	35 90	8	$\frac{6}{8}$	34.83	$02\frac{1}{2}$	1,125
32 10	35 90	4	$\frac{7}{8}$	40 64	$1\frac{1}{2}$	1.160
32 10	35.90	...	$\frac{8}{8}$	46.45	4	1,210

The slags showed little fluidity and became sticky toward the end of the series. They were all opaque, dark-brown to black on the fracture, and lighter brown on the surface. The luster was sub-metallic to vitreous. All the slags were magnetic.

TABLE XV.—The Effect of Replacing CaO with MgO and ZnO. (Figure 9, Curve V.)

Composition of Slag, in Grams.						Melting Point.	
SiO_2.	FeO.	CaO.		MgO.	ZnO.		
		Remaining.	Replaced.	Replacing.	Replacing.	Seger cone. No.	Degrees. C.
32 10	35.90	32	...	0.000	0.000	1	1,150
32 10	35 90	28	$\frac{1}{8}$	1.436	2 903	3	1,190
32 10	35.90	24	$\frac{2}{8}$	2 874	5.805	$1\frac{1}{2}$	1,160
32 10	35.90	20	$\frac{3}{8}$	4 310	8.708	$01\frac{1}{2}$	1,140
32 10	35 90	16	$\frac{4}{8}$	5 748	11.61	03	1.110
32 10	35.90	12	$\frac{5}{8}$	7 184	14.51	$03\frac{1}{2}$	1,120
32 10	35 90	8	$\frac{6}{8}$	8 622	17.42	02	1.130
32 10	35 90	4	$\frac{7}{8}$	10 06	20 32	1	1,150
32 10	35.90	...	$\frac{8}{8}$	11 49	23 22	6	1,250

The fluidity of the slags varied considerably; the most fluid were Nos. 3 and 4; then followed Nos. 2 and 5, 1 and 6, 7 and 8. The slags were opaque, uniformly black on the fracture, but brownish on the surface. The luster was sub-metallic to vitreous, and all the slags were noticeably magnetic.

TABLE XVI. — THE EFFECT OF REPLACING CaO WITH BaO AND ZnO.
(Figure 9, Curve VI.)

Composition of Slag, in Grams.						Melting Point.	
SiO_2.	FeO.	CaO.		BaO.	ZnO.		
		Remaining.	Replaced.	Replacing.	Replacing.	Seger cone. No.	Degrees. C.
32.10	35.90	32	...	0.00	0.000	1	1,150
32.10	35.90	28	$\frac{1}{8}$	5.47	2.903	1	1,150
32.10	35.90	24	$\frac{2}{8}$	10.94	5.805	$02\frac{1}{2}$	1,120
32.10	35.90	20	$\frac{3}{8}$	16.41	8.708	$03\frac{1}{2}$	1.100
32.10	35.90	16	$\frac{4}{8}$	21.88	11.61	03	1.090
32.10	35.90	12	$\frac{5}{8}$	27.35	14.51	06	1.030
32.10	35.90	8	$\frac{6}{8}$	32.83	17.42	07	1.010
32.10	35.90	4	$\frac{7}{8}$	38.30	20.32	07	1.010
32.10	35.90	...	$\frac{8}{8}$	43.77	23.22	$07\frac{1}{2}$	1,020

Although these slags formed readily, they did not flow at all at their formation temperatures. They were opaque. The color, which was at the beginning of the series a dark steel-gray, became brownish-black towards the end. The luster was sub-metallic to vitreous. Slags running high in CaO were distinctly magnetic; those containing much BaO and ZnO, only slightly so. The slags forming below 1.030° C. began to fuse before all the carbon dioxide of the barium carbonate had been driven off. They were spongy, and more brownish than those forming at higher temperatures.

TABLE XVII. — THE EFFECT OF REPLACING CaO WITH MgO, BaO AND ZnO.
(Figure 9, Curve VII.)

Composition of Slag, in Grams.							Melting Point.	
SiO_2.	FeO.	CaO.		MgO.	BaO.	ZnO.		
		Remaining.	Replaced.	Replacing.	Replacing.	Replacing.	Seger cone. No.	Degrees. C.
32.10	35.90	32	...	0.00	0.000	0.000	1	1,150
32.10	35.90	28	$\frac{1}{8}$	0.958	3.647	1.922	1	1.150
32.10	35.90	24	$\frac{2}{8}$	1.916	7.295	3.845	$01\frac{1}{2}$	1.140
32.10	35.90	20	$\frac{3}{8}$	2.874	10.94	5.767	02	1.110
32.10	35.90	16	$\frac{4}{8}$	3.831	14.59	7.690	03	1.090
32.10	35.90	12	$\frac{5}{8}$	4.789	18.24	9.612	04	1,070
32.10	35.90	8	$\frac{6}{8}$	5.747	21.88	11.535	04	1.070
32.10	35.90	4	$\frac{7}{8}$	6.705	25.53	13.46	01	1.130
32.10	35.90	...	$\frac{8}{8}$	7.663	29.18	15.38	$3\frac{1}{2}$	1,200

None of the slags are fluid; all are opaque, grayish-black on the fracture, dull brown on the surface; sub-metallic to vitreous in luster, and attracted by the magnet.

It will be seen that there is a great similarity in the general physical properties of these slags: at least the differences are not sufficiently great to give to the several numbers of the series any special characteristics.

3. *Discussion of Temperature Curves* (Figure 9). — In Figure 9 the abscissa gives in eighths the proportion of CaO replaced by the different oxides; the ordinate, the temperature in degrees C.

Curve I (CaO replaced by MgO) shows clearly that as soon as MgO begins to replace CaO, the formation temperature rises very decidedly above that of the basal slag, 1,150° C. With $\frac{1}{8}$ of the CaO replaced, the temperature rises to 1,210° C.; it then sinks until $\frac{2}{8}$ is replaced (1,190° C.), and rises again until $\frac{4}{8}$ has been reached (1,240° C.); after a second depression to 1,190° C. (with $\frac{5}{8}$ CaO replaced), it rises steadily to 1,400° C., when MgO has been substituted for all of the CaO. While the curve shows rises and falls, it always remains above the line of the basal slag — a fact which explains the aversion of many smelters to the use of a dolomitic limestone as flux.

Curve II (CaO replaced by BaO) shows that, as MgO raises the formation temperature, so BaO lowers it, only that the curve shows more regularity. The melting point descends steadily with the increase of BaO, until $\frac{6}{8}$ of the CaO has been thus replaced, when a minimum is reached at 985° C.; but even when all the CaO has been taken away, the temperature rises only to 1,010° C. The curve shows BaO to be a powerful flux. This fact will be again seen clearly further on, in the results of combining BaO with other refractory oxides, as it straightens out their curves and lowers their melting points. (See Curves III, VI, and VII).

Curve III (CaO replaced by MgO and BaO) shows that MgO, replacing CaO, raises the formation temperature of the basal slag, and gives an irregular curve; but as soon as BaO is substituted for part of the MgO, the curve becomes more regular, and the melting point is decidedly lowered, or, in other words, BaO promotes the slagging of MgO. Thus, when $\frac{1}{8}$ of the CaO was replaced by MgO alone, the formation temperature rose from 1,150° C. to 1,210° C.; but when one-half of the MgO is replaced by BaO, the temperature sinks to 1,135° C., and continues to sink with the increase of the two constituents until the minimum has been reached at 1,055° C., with a substitution of $\frac{6}{8}$ of the CaO. After that the temperature rises, but remains below the curve of the basal slag.

Curve IV (CaO replaced by ZnO) illustrates by its peculiar form some of the difficulties that smelters encounter in treating zincose ores. At first the melting point is lowered ($\frac{1}{8}$ replacement giving

1,130° C.); but it then rises, crosses the curve of the basal slag, and reaches a first maximum at 1,240° C. when ZnO has been substituted for $\frac{4}{8}$ of the CaO; then it descends below the line of the basal slag to a minimum, at 1,125° C., and finally rises quickly to the second and last maximum, at 1,210° C. Some metallurgists hold that most of the ZnO is held in igneous solution by a slag; others (*e.g.*, Dr. Iles[1]), that most, if not all of the ZnO is slagged, as are the other bases. The very irregular form of Curve IV seems to indicate that both opinions have their justification, *i.e.*, that the presence or absence of other metallic oxides, besides FeO and CaO, may promote or obstruct the scorification of ZnO. The curve, taken by itself, indicates that in some cases more ZnO was slagged than in others.

Curve V (CaO replaced by MgO and ZnO) seems to bear out the opinion held by smelters generally that MgO and ZnO in a slag intensify its refractory properties. MgO alone (Curve I) raised the formation temperature throughout, though not uniformly; ZnO (Curve IV) sometimes raised it and sometimes lowered it; MgO and ZnO do not give a resultant average of their peculiarities; sometimes one predominates, sometimes the other. In Curve V, with $\frac{1}{8}$ and $\frac{2}{8}$ replacement, the temperature follows the magnesia curve (I); with $\frac{2}{8}$ to $\frac{5}{8}$ replacement, it goes just in the opposite direction of the magnesia — as well as of the zinc-oxide curve (IV), and with $\frac{5}{8}$ to $\frac{8}{8}$ replacement, it has a tendency to follow the zinc-oxide curve.

Curve VI (CaO replaced by BaO and ZnO) clearly illustrates the great effect of BaO as a flux. Its general trend is similar to that of the BaO curve (II), only the temperatures lie a little higher. The great irregularity of the zinc-oxide curve has been nearly wiped out, or, in other words, BaO greatly promotes the slagging of ZnO. As the curve shows, $\frac{1}{8}$ replacement leaves the melting point of the basal slag unchanged; further substitutions lower the melting point until the minimum of 1,010° C. is reached, with $\frac{6}{8}$ of the CaO replaced. In the lowering of the temperature, the two curves (VI and II) are first approximately parallel, as far as $\frac{2}{8}$ replacement; then the refractory nature of ZnO begins to assert itself, until $\frac{4}{8}$ of the CaO has been removed; but further on it yields again, more and more, to the fluxing power of BaO.

Curve VII (CaO replaced by MgO, BaO and ZnO) is another instance of the fluxing power of BaO. The curve of MgO, ZnO (V)

[1] School of Mines Quarterly, xix, p. 197.

showed ups and downs which could not be well harmonized with either the curve of MgO (I) or that of ZnO (IV); but as soon as BaO is added, we obtain a curve that is quite regular. Thus, with $\frac{1}{8}$ replacement, the formation temperature of the basal slag is not changed; but with further reductions of CaO, the temperature is steadily lowered to the minimum of 1,070° C., with a replacement of $\frac{5}{8}$ to $\frac{6}{8}$ of the CaO, after which it quickly rises to a maximum of 1,200° C. The refractory effect of MgO is clearly shown by Curve VII, which, with one exception, always indicates higher temperatures than Curve VI.

4. *Replacement of Slag Constituents by Al_2O_3.*

Tables XVIII to XXI, inclusive, give the charges used in studying the effects produced on the formation temperature of a slag by the replacement with Al_2O_3 of the three constituents SiO_2, FeO and CaO. The general plan of substitution is the same as was followed in Tables XI to XVII. Figure 10 gives a graphical representation of the results.

TABLE XVIII.—THE EFFECT OF REPLACING SiO_2 WITH Al_2O_3. (Figure 10, Curve I.)

Composition of Slag in Grams.					Melting Point.	
SiO_2.		Al_2O_3.	FeO.	CaO.		
Remaining.	Replaced.	Replacing.			Seger cone. No.	Degrees. C.
32.10	...	0.000	35.90	32	1	1,150
28.09	$\frac{1}{8}$	4.525	35.90	32	$1\frac{1}{2}$	1,160
24.07	$\frac{2}{8}$	9.050	35.90	32	2	1,170
20.06	$\frac{3}{8}$	13.57	35.90	32	3	1,190
16.05	$\frac{4}{8}$	18.10	35.90	32	$4\frac{1}{2}$	1,220
12.04	$\frac{5}{8}$	22.62	35.90	32	8	1,290
8.025	$\frac{6}{8}$	27.14	35.90	32	...	.....
4.012	$\frac{7}{8}$	31.66	35.90	32	...	.....
0.000	$\frac{8}{8}$	36.20	35.90	32	...	.....

All these slags show a lack of fluidity. They are opaque, from dark-gray to black on the fracture, and dull reddish brown on the surface. The last slag of which the formation temperature could be determined had a dark steel-gray surface, which is characteristic of all slags running very high in Al_2O_3. The luster of all the slags was dull to slightly vitreous, and all were attracted by the magnet; but the magnetism diminished as Al_2O_3 increased.

TABLE XIX.—THE EFFECT OF REPLACING FeO WITH Al_2O_3. (Figure 10, Curve II.)

Composition of Slag, in Grams.					Melting Point.	
SiO_2.	FeO.		Al_2O_3.	CaO.		
	Remaining.	Replaced.	Replacing.		Seger cone. No.	Degrees. C.
32.10	35.90	...	0.000	32	1	1,150
32.10	31.41	$\frac{1}{8}$	2 121	32	1	1,150
32.10	26.93	$\frac{2}{8}$	4 242	32	$01\frac{1}{4}$	1,135
32 10	22 44	$\frac{3}{8}$	6 363	32	$1\frac{1}{4}$	1.155
32.10	17.95	$\frac{4}{8}$	8 485	32	2	1,170
32 10	13.46	$\frac{5}{8}$	10 586	32	3	1.190
32.10	8.975	$\frac{6}{8}$	12 72	32	5	1,230
32 10	4.487	$\frac{7}{8}$	14.84	32	...	.....
32.10	0.000	$\frac{8}{8}$	16.97	32	...	.....

These slags are all fairly fluid, especially the two melting at 1,155° and 1,170° C. They are opaque, dull brown on the fracture when little Al_2O_3, and dark-gray when much Al_2O_3 is present, and dull reddish brown on the surface. The luster is dull to slightly vitreous, and magnetism is noticeable, especially with a low percentage of Al_2O_3.

TABLE XX.—THE EFFECT OF REPLACING CaO WITH Al_2O_3. (Figure 10, Curve III.)

Composition of Slag, in Grams.					Melting Point.	
SiO_2.	FeO.	CaO.		Al_2O_3.		
		Remaining.	Replaced.	Replacing.	Seger cone. No.	Degrees. C.
32 10	35.90	32	...	0.000	1	1,150
32 10	35.90	28	$\frac{1}{8}$	2.430	$01\frac{3}{4}$	1,145
32.10	35.90	24	$\frac{2}{8}$	4.860	02	1,110
32.10	35 90	20	$\frac{3}{8}$	7.290	$01\frac{1}{2}$	1,140
32 10	35.90	16	$\frac{4}{8}$	9.720	$01\frac{1}{4}$	1,135
32 10	35.90	12	$\frac{5}{8}$	12 15	$01\frac{1}{2}$	1,140
32.10	35.90	8	$\frac{6}{8}$	14 58	1	1,150
32.10	35.90	4	$\frac{7}{8}$	17.01	4	1,210
32.10	35.90	...	$\frac{8}{8}$	19.44	$4\frac{1}{2}$	1,220

None of the slags are fluid; on the contrary, they have a tendency toward viscosity; especially with a high percentage of Al_2O_3. They are opaque, grayish-black to black on both fracture and surface, and slightly vitreous in luster. The magnet attracts them somewhat—those high in Al_2O_3 less than those high in CaO.

TABLE XXI. — THE EFFECT OF REPLACING FeO AND CaO WITH Al_2O_3.
(Figure 10, Curve IV.)

Composition of Slag, in Grams.						Melting Point.	
SiO_2.	FeO.		CaO.		Al_2O_3.		
	Remaining.	Replaced.	Remaining.	Replaced.	Replacing.	Seger cone. No.	Degrees. C.
32.10	35.90	...	32	...	0.000	1	1,150
32.10	33.66	$\frac{1}{16}$	30	$\frac{1}{16}$	2.275	3	1,190
32.10	31.41	$\frac{2}{16}$	28	$\frac{2}{16}$	4.550	2	1,170
32.10	29.17	$\frac{3}{16}$	26	$\frac{3}{16}$	6.825	$1\frac{1}{2}$	1,160
32.10	26.93	$\frac{4}{16}$	24	$\frac{4}{16}$	9.100	1	1,150
32.10	24.69	$\frac{5}{16}$	22	$\frac{5}{16}$	11.37	$01\frac{1}{4}$	1,145
32.10	22.44	$\frac{6}{16}$	20	$\frac{6}{16}$	13.65	1	1,150
32.10	20.20	$\frac{7}{16}$	18	$\frac{7}{16}$	15.92	2	1.170
32.10	17.95	$\frac{8}{16}$	16	$\frac{8}{16}$	18.20	9	1,310

None of these slags are very fluid; the mixtures with 9.10 and 11.37 grams of Al_2O_3 were the most so; mixtures with 15.92 and 18.20 grams of Al_2O_3 least so. The slags were opaque, grayish-brown to black on the fracture, and dark-brown, more or less tinged with red, on the surface; sub-metallic to vitreous in luster, and all noticeably attracted by the magnet.

The general physical properties show no characteristic points, except that some slags appear to be more fluid than others. If the formation temperatures of these slags are favorable, they deserve consideration in the smelting of aluminous ores.

5. *Discussion of Temperature Curves* (Figure 10). — In Figure 10 the abscissa again represents the proportions of the different constituents replaced by Al_2O_3, and the ordinate the temperature in degrees C.

Curve I (SiO_2 replaced with Al_2O_3) shows that the replacement of SiO_2 with Al_2O_3 raises the formation temperature of the basal slag in an increasing ratio: $\frac{1}{8}$ replacement giving 10° C.; $\frac{2}{8}$ replacement, 20° C.; $\frac{3}{8}$ replacement, 40° C.; $\frac{4}{8}$ replacement, 70° C.; and $\frac{5}{8}$ replacement, 140° C. increase of this temperature. Mixtures with a higher percentage of Al_2O_3 could not be fused.

The curve proves that, in treating aluminous ores, Al_2O_3 cannot be simply substituted for SiO_2, as has often been advocated, without raising the melting point. The contrary procedure will be the right one, namely, that of keeping the percentage of SiO_2 high.

Curve II (FeO replaced with Al_2O_3) shows that, first, with $\frac{1}{8}$ replacement, Al_2O_3 does not change the formation temperature of the basal slag. More Al_2O_3 first lowers it somewhat (to 1,135° C. with $\frac{2}{8}$ replacement), but raises it again, quickly and pretty uniformly, until after a replacement of $\frac{6}{8}$ of the FeO, a mixture is obtained

which will not fuse at 1,430° C., the temperature indicated by Seger cone No. 15.

The curve shows that only small portions of the FeO can be replaced by Al_2O_3 without raising the formation temperature to too high a point. It proves also that the rule, to keep both SiO_2 and CaO high in the presence of Al_2O_3, can be applied within narrow limits only.

Curve III (CaO replaced with Al_2O_3) shows that by substituting Al_2O_3 for CaO, the melting point of the basal slag is lowered until $\frac{6}{8}$ of the CaO has been replaced, when the formation temperature rises suddenly. With the exception of the great depression of the curve to 1,110° C., when $\frac{2}{8}$ of the CaO has been replaced, the lowering of the formation temperature by progressive replacement up to $\frac{6}{8}$ averages only 10° C. This proves that figuring Al_2O_3 into a slag as replacing CaO is a justifiable proceeding. A combination of Curves I and III suggests that if part of the SiO_2 and CaO were replaced by Al_2O_3, the formation temperature of the basal slag would remain the same. This is a favorite method in the smelting of the highly aluminous Cripple Creek gold ores in Colorado lead blast furnaces, and gives most satisfactory results.

Curve IV (FeO and CaO replaced with Al_2O_3) is so irregular in general trend, and so different from the three preceding curves, as to suggest that the substitution of Al_2O_3 for both FeO and CaO has no practical value. By replacing only $\frac{1}{16}$ of FeO and CaO with Al_2O_3, the formation temperature is raised 40° C.; upon increasing the Al_2O_3 to $\frac{5}{16}$, the temperature falls below the line of the basal slag, coming to a minimum at 1,145° C. With further addition of Al_2O_3, it rises suddenly, reaching 1,310° C., with $\frac{8}{16}$ of FeO and CaO replaced by Al_2O_3.

VIII. Conclusion.

In all the experiments only the formation temperatures were carefully measured, as above described. As far as was possible with the small samples, the general physical properties, including fluidity, were observed. Many mixtures which were changed into slags at comparatively low temperatures may not be suited for practical slags on account of their viscosity at the temperatures at which they were formed, and would require considerable superheating to make them sufficiently fluid to run easily and permit a satisfactory separation of the valuable end product or intermediary product from the waste.